COMMENTARY ON J. BRONOWSKI'S "NEW CONCEPTS IN THE EVOLUTION OF COMPLEXITY"

by Ralph Wendell Burhoe

When I first read Bronowski's manuscript on "New Concepts in the Evolution of Complexity," I considered it to be the most significant document on life's (and death's) place in the scheme of things since Erwin Schrödinger's *What Is Life?*[1] However, I wish to make two points which Bronowski urged me to publish with his paper: I suggest that his statement on Polanyi's notions might be modified; and I would suggest a fruitful relation between Bronowski's notion of "stratified stability" and the concept of "natural selection."

A. On Polanyi

Bronowski indicates that Polanyi's "argument is intended to show that man (and any other living form) is not simply a machine" (p. 27). Perhaps Polanyi may have said something like that somewhere, but in his more recent statements he has been arguing that it is exactly because man is a machine that he cannot be explained by physics and chemistry.

In the version of Polanyi's argument which was presented to the 1967 symposium of the AAAS in New York, and published in the December 1968 issue of *Zygon,* he said: "the organism is shown to be, like a machine, a system under dual control. Its structure serves as a boundary condition, harnessing the physicochemical processes by which its organs perform their functions."[2]

Moreover, just because it is an artifact like a machine, the organism is not explicable by physics. The "information content of a DNA molecule inheres in an ordering of its constituents which is not due to any physical interaction between them. It is a boundary condition, and as such, it is extraneous to the chemical forces composing the molecule, just as if their pattern were artificial, as that of a machine is."[3]

If this is Polanyi's latest position, I suggest it would be better to respond to him on this ground than on some ground which he does not now hold. Since Polanyi's argument is that the structure and func-

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tioning of the cell (including its genetic base) are not informed or explained by the laws of physics and chemistry alone but require also the boundary conditions, such as the information encoded in the DNA, it seems to me the argument between Bronowski and Polanyi at the level of a cell is essentially based on a different usage of terms. If one allows Polanyi's definition that boundary conditions are not a part of physics and chemistry, then he is right. But I agree with Nagel[4] and others that the laws of physics and chemistry are not the whole of what physicists and chemists ordinarily use in doing physics and chemistry; they customarily, even necessarily, also use the boundary conditions, the empirical givens which the laws by themselves do not supply. If a cell has a certain DNA structure and a certain consequent present state, this boundary condition is as much a part of its physics as are the boundary conditions of a falling body at some time (t_0) from which its further states are to be explained by the law of falling bodies.

Strictly speaking, in terms of the understanding of physics that I suppose most applied physicists hold, Polanyi is incorrect in his statement that the ordering of the constituents of a DNA molecule is not due to the physical interaction among them. Most physicists would grant the boundary conditions, namely, the present DNA molecule, and then affirm that its duplication reactions are strictly determined by the physical interactions among its parts as they interact with the typical cellular environment (which also involves a special boundary condition). What Polanyi is saying is only true for the sophisticated physicist who would say that he supposed if there were a random mixing of these same atoms, they would not have any significant probability of immediately finding themselves ordered in a way even closely corresponding to the order of the DNA molecule which is the genetic information. But by saying this Polanyi is begging the question. A random assortment of atoms is not the starting point for a physical explanation of what goes on in the cell. Most workers in the field assume that the boundary conditions of the present state of the DNA and the present state or boundary conditions of the cell are a part of their analysis, along with the "laws" which state what will happen when you are given those boundary conditions.

I think that Bronowski's paper would be strengthened by substituting something like the above argument that, at the cellular level, the quarrel or difference with Polanyi is primarily semantic. Polanyi is giving a different if not an uncommon definition to physics and chemistry when he includes only the laws and not the boundary conditions. All would admit that the DNA and the structure of the cell do, in fact, provide special boundary conditions for the operation of the

laws of physics and chemistry within the cell that define the life of the cell. And the explanation of the origin of the boundary conditions is not necessarily a part of the physical explanation of events in the cell, if we accept as the starting point for our explanation (our deductive statements or mathematical equations) the already existing, empirically given, boundary conditions to insert into our logical formula or law. To explain Niagara Falls, we could accept without explanation the given riverbed and escarpment as the boundary conditions and apply the law by which gravity operates on a stream of water to explain the falls.

But Bronowski is pointing to a very different level of analysis from the one that Polanyi is pointing to. Bronowski is saying that the boundary conditions themselves are byproducts of a history of events operating under physical laws, where the present boundary conditions can be explained as the result of a lawful succession of events from previous states over long periods. The escarpment which is the boundary condition for Niagara Falls can itself become explained in terms of physical laws operating over thousands of years. "Reductionism is valid and sufficient when it is an *historical* explanation, so that it presents a temporal and logical sequence of steps by which the result has been reached. . . . So it is valid to regard an organism as an historical creation whose plan [boundary conditions] is explained by its evolution" (pp. 27–28).

Bronowski is detailing the kinds of strata of stability which are empirically given in the world and by which we can understand how the operations of random energy must necessarily build successively higher levels of stable systems. Thus transitions between successive levels of stable boundary conditions may be reduced in time back from those of the highest levels of human cultural evolution to those of geophysics and geochemistry without breaking the continuity of explanation—providing you allow in your explanation for the changes in states that may take a cumulation of a few thousand million years of history on earth.

Of course, scientists, aware of the Gödel theorem and other limitations on explanatory systems, are not likely to assert that they can explain history back to its ultimate source. Basically, it seems to me this is what Polanyi is saying when his argument is carefully analyzed: that physics cannot explain ultimates—that is, it cannot explain the ultimate boundary conditions or empirical givens on which all our knowledge (including physical laws) is ultimately dependent. I do not think any good scientist would disagree with him on this.

This leads me to my second suggestion with regard to the paper.

B. THE PRINCIPLES IN THE CONCEPT OF EVOLUTION

Bronowski's basic victory over those who would assert the impotence of physics to explain life is his demonstration that physics can explain not only what is going on in the cell, given the boundary conditions, but also the rise of the special boundary conditions of biological life from the more basic boundary conditions of nonliving physical systems, provided the explanation involves a sufficiently long history or evolutionary time span. Central to this is his concept of "stratified stability," which in a beautiful manner not only clarifies the role of physics in natural selection but clarifies and makes meaningful the relationship of life and evolution to the second law of thermodynamics, where I did not find Bertrand Russell, or Norbert Wiener, or even Erwin Schrödinger so successful.

Because this concept of "stratified stability" is so important for the discussion, my second suggestion is that its relation to the concept of "evolution" might be stated a little more carefully. Bronowski lists five distinct principles, and since he does not in the paper give much information on the first three and since I, as a reader, am one of those who are familiar with some of the contemporary trinitarian formulations of evolutionary principles, I wonder if a revision of this would not help make the paper more powerful in the evolutionary community.

The trinity of principles with which I am familiar in the so-called synthetic evolutionary theories now current has been nicely put by George Wald in his "Origins of Life":[5] "a mechanism of inheritance . . . ; a continuous intrusion of 'noise' into the genetic message, appearing in the offspring as random inherited variations (mutations); and the struggle for existence." Sometimes the trinity is expressed as replication, variation, and selection.

I find it difficult to know why Bronowski needs his "(*a*) family descent" as well as his "(*c*) Mendelian inheritance." I would suppose (*a*) is a part of (*c*) and wonder why these two could not be combined into one, under the general category of "mechanism of inheritance" or "replication"?

I have no problem with his "(*d*) fitness for change," which is another way of saying "variation" or "noise" or "error."

But I have a question concerning the relation or distinction between Bronowski's "(*b*) natural selection" and "(*e*) stratified stability." If I am not mistaken, Bronowski, in his concept of "stratified stability," has at last given a neat physical formulation that underlies all levels of the selective or adaptive process in evolution from atoms to human

cultural patterns. Wald, in the above-cited paper, implies such a working of the selective scheme and gives a rich picture of how an isomer, which is "improbable, intrinsically unstable" in the context of lower levels or strata of stability, nevertheless has rare qualities that make it a factor of the stability level in the context of organisms requiring visual processes, such that 11-*cis* retinine captures and converges on itself the visual mechanisms (and the DNA codes necessary to produce and maintain them) that have evolved independently in three different phyla on Earth.[6] However, I do not know that Wald has generalized the picture in such terms as Bronowski's "preferred configurations" or "hidden stabilities" and shown how they make sense in terms of the relation of the evolution of life to the second law of thermodynamics. I find Bronowski has here given a beautiful generalization of a physical (and universal) basis of natural selection, including the natural selection of the open systems (cybernetic machines) that evolve negentropically.

If I am right that the concept of "stratified stability" is a more comprehensive statement of "natural selection," then Bronowski could reduce his five principles to the current three of some contemporary evolutionary theories, in which his "stratified stability" would provide a generalized and physical model of how the natural selection process works at all levels.

NOTES

1. Erwin Schrödinger, *What Is Life?* (Cambridge: Cambridge University Press, 1944; New York: Doubleday Co., 1956).
2. Gerald Holton et al., "Do Life Processes Transcend Physics and Chemistry?" *Zygon* 3 (1968):446.
3. Ibid., p. 447.
4. See Nagel's comments, ibid., p. 445.
5. George Wald, "Origins of Life," *Proceedings of the National Academy of Sciences* 52 (1964):595–611.
6. See ibid., p. 608.