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COMMENTARY

THE AUTONOMY OF BIOLOGY: THE POSITION OF BIOLOGY AMONG THE SCIENCES

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ABSTRACT

Philosophers of science have claimed that the position of biology among the sciences is the most prominent and controversial issue of the philosophy of biology. Some authors consider biology merely a "province" of physics and reducible to physics, others uphold the autonomy of biology, while still others have decided that biology lacks the rigor to justify being considered a genuine science. In my own analysis of this problem, I have concluded that the science of biology has all the attributes of a genuine science, as well as a number of other characteristics restricted to biology. These characteristics are listed and discussed. They justify ranking biology as an autonomous science, just as autonomous as physics and many other sciences.

SCIENCE, as we understand it, dates from the Scientific Revolution, that remarkable achievement of the human intellect characterized by the work of Copernicus, Galileo, Kepler, Newton, Descartes, and Leibniz. At that time the basic principles of the scientific method, which still largely characterize science, were developed. What one considers science to be is, of course, a matter of opinion. In some respects Aristotle's biology was also science, but it lacked the methodological rigor and comprehensiveness of the science of biology as it developed from 1830 to 1860.

The disciplines that gave rise to the prevailing concept of science during the Scientific Revolution were mathematics, mechanics and astronomy. How large a contribution scholastic logic made to the original framework of this physicalist science has not yet been determined; it certainly played a large role in the thinking of Descartes. Biology could not make a substantial contribution because it did not yet exist as such. The living world at that time was considered to belong to the realm of medicine; this was true not only for anatomy and physiology, indeed, but even for botany, which largely consisted of the identification of medicinally important plants. To be sure, there was also some natural history, but it either had the nature of a hobby or it was pursued in the service of natural theology. In retrospect, it is quite evident that some of this early natural history was actually very good science, but not being recognized as such at that time, it did not contribute to the early philosophy of science.

Was it an accident of history that mechanics, through the efforts of Galileo and his followers, was the first science to develop a set of principles and laws? Perhaps not, because mechanics may well be the simplest of all the sciences, and thus best suited for the development of some simple laws and principles. When the other branches of physics devel-

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oped, exceptions to the universal laws and to the expected determinism of mechanics were found again and again, requiring various modifications. Indeed, in everyday life the laws of mechanics are often so completely thwarted by stochastic processes that determinacy appears to be totally absent. For instance, so much turbulence usually accompanies the movement of air masses and water masses that the laws of mechanics do not permit absolute long-term predictions in either meteorology or oceanography.

The priority of mechanics during the Scientific Revolution had an unfortunate consequence for biology. Because it was accepted as the exemplar of science, the mechanists naively assumed that the laws and principles derived from mechanics were valid for all of science. Actually this is not at all true for certain principles, later bracketed under the term "physicalism"; an example is the view that all nature obeys a single set of laws, and that therefore organisms are in no way different from inert matter. From this it followed logically, as stated by Francis Crick (1966), that "the ultimate aim [of science] . . . is in fact to explain all biology in terms of physics and chemistry" (p 10).

In due time developments in biology made this position untenable. The long controversy between the mechanists and the vitalists ended by the conclusion that both of these attempts to explain life were erroneous and should be replaced by the term *organicism*. Organicism rejected vitalism and metaphysics, but insisted that organisms are ordered systems with a number of characteristics, such as the possession of a genetic program, which distinguishes them fundamentally from any nonliving system.

The development of organicism had a profound impact on the position of biology among the sciences, an impact not yet fully appreciated by most philosophers of science. As a result, after the middle of the 20th century, one could discern three very different views on the position of biology. According to one extreme, biology is to be excluded from science because it lacks the universality, the law-structuredness, and strictly quantitative nature of a "true science" (meaning physics). According to the other extreme, biology not only has all the necessary attributes of a genuine science, but differs from physics in such important respects that it is to be ranked as an autonomous science, equivalent to physics. Finally, there is an intermediate viewpoint, which accords to biology the status of a science but considers it, after due reduction, as nothing but a province of the physical sciences. The existence of these three incompatible viewpoints is responsible for the fact that the question "whether and how biology differs from the other natural sciences . . . is the most prominent, obvious, frequently posed, and controversial issue the philosophy of biology faces" (Rosenberg 1985:13). The details of this controversy and the names of the authors involved are given in the writings of Munson (1975), Ruse (1973), and Rosenberg (1985).

The Question of an Autonomy of Biology

Traditionally, most of those who dealt with living organisms, or with their functions, rejected reductionism. Instead, they continued an ancient tradition that had been quite strong among the Greeks (including Plato and Aristotle), which ascribed to organisms, even to plants, some sort of "soul" — that is, some property not encountered in inanimate matter. All those who shared this belief were usually lumped together under the term "vitalists."

These vitalists claimed consistently that the science of life had nothing to do with physics and that it was an autonomous field. Did this position become untenable when a strictly physicochemical explanation of all physiological processes was adopted? Two answers were given to this question. The mechanists answered it affirmatively by claiming that one could now incorporate biology in a philosophy of physics by "reducing" all the complexities of biology to the more elementary level of physics. This is what Mainx (1955) and Ruse (1973) attempted to do, and their conclusion was apparently accepted by most logical positivists and postpositivist (empiricist) philosophers. Vitalism postulated immaterial forces and often provided metaphysical interpretations; both were clearly incompatible with the accepted concept of science since the Scientific Revolution.

For mechanists, organisms were simply characterized by matter and motion, and differed in no significant way from the inanimate objects dealt with by physics. When organicism, the new holistic philosophy of biology, developed in the 20th century, particularly under the influence of Darwinism, the previous polarity became invalid. However, organicism ascribed the autonomous properties of organisms not to immaterial forces, but to the ordered structure of their systems, and to their possession of an historically acquired genetic program. This conclusion necessitated the development of a new conceptual framework, and of new approaches to theory construction and methodology, resulting in a greatly modified biology and philosophy of science (Simpson 1964; Ayala 1968; Mayr 1969, 1988).

The changes necessitated by the rise of organicism were largely ignored by physicalist philosophers. They ignored the fact that organicism, in its rejection of immaterial forces and metaphysical explanations, is actually closer to physicalism than to vitalism. Yet, one might ask, is not this relation to physicalism close enough to invalidate the claim for an autonomy of biology? It becomes quite obvious at this point that some semantic clarification is necessary.

Let me begin with the issue of "Whether or not biology is a science like the sciences of physics and chemistry?" (Ruse 1973:10). Although this is actually a somewhat ambiguous question, it can be clarified by subdividing it into two questions:

1) Is biology, like physics and chemistry, a science?

2) Is biology a science exactly like physics and chemistry?

What characteristics must an area of knowledge have in order to qualify as science? The list usually includes (among others): an effort to achieve absolute objectivity; the rejection of authority; the rejection of immaterial forces and of metaphysical or supernatural explanations; the consistent effort to relate individual phenomena to broader generalizations or principles (sometimes referred to as laws); the testing of provisional explanations (conjectures and hypotheses) by observation, comparison or experiment; and the simplification of the bewildering diversity of natural phenomena by subsuming them under a limited number of explanatory theories.

The truly defining characteristics of science were not yet clearly seen at the time of the Scientific Revolution, when the traditional concept of science was developed, because only two disciplines—mechanics and astronomy—served as the exemplars of science, and biology provided no appreciable input. It was not realized until several hundred years later that the philosophy of science—from Descartes, Locke and Kant to Carnap, Nagel and Hempel, and up to the postpositivists—was based on two sets of criteria: those which have to be met by any scholarly activity striving to qualify as genuine science, and those merely pertaining to physicalism, with limited validity outside the physical sciences. Not surprisingly, acceptance of these physicalist criteria led to protests by biologists who pointed out that the so-called philosophy of science existing then was nothing but a philosophy of physicalism (Simpson 1964; Mayr 1969). Not only did this physicalist philosophy of science attribute characteristics to biology that are incompatible with highly complex systems, but, more importantly, it ignored large parts of biology, such as the whole biology of historically evolved genetic programs—evolutionary biology. At best, it covered only part of biology. To achieve a more universal concept of science, it is necessary to remove the specialized, purely physicalist, features from the science of the Scientific Revolution. This still leaves intact the most characteristic aspects of genuine science.

Moore (1993) has listed eight criteria to help determine whether a certain activity qualifies as science:

(1) It must be based on data collected in the field or laboratory by observation or experiment, without invoking supernatural factors.

(2) Data are collected to permit answering questions, and observations are made to strengthen or refute conjectures.

(3) Objective methods are employed in order to minimize any possible bias.

(4) Hypotheses must be consistent with the observations and must be compatible with the general conceptual framework.

(5) All hypotheses must be tested, and, if possible, competing hypotheses be developed, and their degree of validity (problem solving capacity) be compared.

(6) Generalizations must be universally valid within the domain of the particular science. Unique events must be explicable without invoking supernatural factors.

(7) In order to eliminate the possibility of error, a fact or discovery is fully accepted only if (repeatedly) confirmed by other investigators.

(8) Science is characterized by the steady improvement of scientific theories, by the replacement of faulty or incomplete theories, and by the solution of previously puzzling problems.

If one accepts Moore's criteria as sufficient, then the equality of biology with the physical sciences can be confirmed, since biological science conforms to all eight criteria.

Twentieth-century philosophy of science, from logical positivism to Popper and Quine, placed great emphasis on the logical structure of scientific theory. Here Mainx (1955) and Nagel (1961) agree with Ruse (1973) that "the logical structure of biology is intrinsically the same as the logical structure of physics." This also supports the conclusion about the scientific status of biology. Simply to ignore (as it does) all the opposing evidence does not justify any denial of the autonomy of biology. If we accept the position that biology shares the logical structure that makes physics a science, does this permit relegating biology to provincial status?

Is Biology a Provincial Science?

Some authors have attempted to demean biology by claiming that it did not really deserve the name "science," because it was at best a "provincial science." Unfortunately, the term "provincial science" was used in two rather different ways. When it was first introduced, it was used as an antonym to "universal," meaning that biology dealt with specific and localized objects about which one could not propose universal laws such as were believed to be a necessary basis of science. The laws of physics, it was said, have no limitations of time or space; they are as valid on the Andromeda Nebula as on Earth. By contrast, biology is provincial, being true only for Earth and also limited in the time dimension. This argument was convincingly refuted by Munson (1975), who showed that none of the fundamental laws, theories or principles of biology are either implicitly or explicitly restricted in their scope or range of application to a certain region of space or time; nor do they contain individual names or other individual constants.

There is a great deal of uniqueness in the world of life. But even though each species is unique, this does not in the least mean that one cannot make all sorts of generalizations about phenomena, such as species. Each ocean current may also be unique, yet we can establish laws and theories about ocean currents.

How valid is the argument that the restriction of known life to Earth deprives biological principles of all universality? Here we must ask, what is the meaning of "universal"? Since inanimate matter is known to exist outside the earth, the science of inanimate matter must also be applicable extraterrestrially, in order to be universal. Since life (so far) has been demonstrated only for Earth, its laws and principles are universal for the known domain of its existence. I can see no reason for withholding the designation "universal" from a principle that is true for the entire domain to which it applies. Our first question can now be answered confidently: Biology clearly qualifies as science. Furthermore, there is no reason to regard it as a "provincial science" as defined above.

This still leaves the second question to be answered: Is biology a science exactly like physics or chemistry? Even those who have answered this question affirmatively (for instance, Mainx and Nagel), have freely admitted that organisms "have characteristics and obey laws that do not occur in the physical sciences" (Nagel 1961:399). Or "that much biology differs from physics in irreconcilable ways" (Rosenberg 1985:25). But Nagel brushes this aside with the claim that these differences are no greater than the ones between mechanics, electromagnetism and chemistry; therefore, "if there is a sound basis for the alleged absolute autonomy of biology, it must be solved elsewhere than in the differences between biology and the physical sciences which have been noted thus far" (p 400).

In the context of the demarcation of biology from the physical sciences, the word "provincial" has also been used at times in a rather different sense from that discussed by Munson. Rosenberg, for instance, states that the opponent of the autonomy of biology "holds that biology is a province of physical science" (1985:16). Evidently physics, in the tradition of the Scientific Revolution, is considered here to be the paradigm of science, and all nonphysical sciences are merely provinces. The autonomy of biology will disappear as soon as "the ultimate aim of the modern [reductionist] movement in biology [has been achieved] . . . to explain all biology in terms of physics and chemistry" (Crick 1966:10).

The autonomist, by contrast, holds that there is no reason why physics should be considered the exemplar of science. To be sure, physics was the first well-organized science, and the first to have emancipated itself from magic, metaphysics and domination by theology. But, says the biologist, there are as many provincial aspects to physics as there are to biology, and an ultimate unity of science can be achieved only if one realizes that universal science contains a number of separate provinces, one of which is physics, another is biology. Many of the attributes of physics are peculiar to physics and will not be found in biology or any other science. In this sense, physics is as provincial a science as is biology. It is evident from these observations how futile it would be to attempt to "reduce" biology, one provincial science, into physics, another provincial science with all of its own peculiarities.

Many, if not most, of the promoters of the unity of science movement were philosophers rather than scientists, and had little realization of the heterogeneity of the sciences. This heterogeneity is true even in any particular science. Let us think of some of the physical sciences: elementary particle physics, solid-state physics, quantum mechanics, classical mechanics, relativity theory, electromagnetism, not to mention geophysics, astrophysics, oceanography, and geology. This heterogeneity increases exponentially when we think of biology and psychology. The impossibility of reducing all these sciences to a single common denominator has been demonstrated again and again during the past 70 years.

THE CHARACTERISTICS OF BIOLOGICAL SCIENCE

It might be helpful to present here a short enumeration of the characteristics of biology not, or only minimally, shared by the sciences of inert matter. This list neither claims completeness nor endeavors to rank the items according to their importance. Yet it comprises the characteristics that justify biology's claim for autonomy. The differences between biology and the physical sciences are sometimes absolute, but for other items they are only quantitative.

A. CONCEPTUAL CHARACTERISTICS

(1) Prevalence of biology-specific concepts, nonreducible to the concepts and theories of the physical sciences.

(2) Antiessentialism. From the time of Pythagoras and Plato on, a concept was almost universally held, that the seemingly unlimited variety of the world consisted actually of a rather limited number of natural kinds (essences, types, eide). The seeming variation is nonessential and accidentally caused by imprecise manifestations of the underlying essence. Each type forms a class defined by its essence; this concept was named essentialism by Popper. Essentialism was illustrated by the example of the triangle. All triangles have fundamentally the same characteristics and are sharply distinguished from quadrangles or any other geometrical figures. There can be no intermediate between a triangle and a quadrangle. All essences are constant and discontinuously separated from all others. By contrast, in biology one does not deal with constant classes, but with variable populations consisting of uniquely different individuals; therefore great emphasis is placed on uniqueness. Antiessentialism also shows that variation provides material for natural selection, with evolutionary changes being populational and therefore prevailingly gradual.

(3) Materialistic explanation of seemingly goal-directed phenomena (teleonomy, adaptedness).

(4) The important explanatory role of historical narratives.

(5) The importance in explanatory schemes of concepts like selection, female choice, competition, succession, and innateness.

(6) The prevalence of indeterminacy owing to the high frequency of stochastic processes, the presence of constraints, the interaction of multiple causes, and the high frequency of chance events; hence a reduced role for prediction.

(7) The relative unimportance of universal laws, owing to the prevalence of probabilism and the limited domain of regularities.

(8) The importance of quality in the properties and actions of organisms, and a correlated reduction in the importance of merely quantitative differences.

B. SPECIAL PROPERTIES OF LIVING ORGANISMS

(9) Presence of an historical constituent in the inherited genetic program; hence legitimacy of "why" questions; capacity for the storage of historical information. This was recognized by Williams (1992) in his establishment of the material on the codical domain in organisms (also see Chapter 6 in Williams).

(10) The enormous complexity of even the simplest organic systems. Everyone knows how complex higher organisms are. Recent researches have discovered, however, that even bacteria possess unexpected complexities. They can form multicellular colonies, in which different cells specialize, and show cooperation and coordination in various activities such as locomotion, feeding and reproduction (Shapiro 1988). Even the simplest living beings are highly complex when compared to inanimate matter.

(11) A high degree of order (organization) in hierarchically organized complex systems, providing abundant scope for emergence, developmental constraints (regulation), and cohesion of the genotype.

(12) Nonconstancy of taxa and other groupings owing to variational evolution.

C. METHODOLOGICAL CHARACTERISTICS

(13) Importance of observation, in addition to experiment.

(14) Importance of the comparative method.

(15) The frequency of independent multiple solutions to the same problem (pluralism).

Nothing illuminates better the difference between the physical sciences and the life sciences than a consideration of the frontiers of biology. When one asks, "Where are the greatest gaps in our understanding of *organisms*," three problems more than any others are usually singled out: the control of differentiation during ontogeny, the workings of the central nervous system, and the interaction of controlling factors in ecosystems.

In each of these problems one deals with enormously complex systems, with a very high number of interacting components, regulatory systems and feedbacks. Whenever it is possible to isolate single components and unitary processes out of these systems, it is found that they are completely explicable by known physicochemical laws. What is still insufficiently understood in all these cases, however, is the regulation of the interaction of such a vast number of components. And this situation illuminates one of the crucial differences between physical and living systems. Nowhere in the inanimate world is there another system to be found — even a complex system — that has the ordered internal cohesion and coadaptation characteristic of even the simplest biological systems.

FURTHER AUTONOMOUS ASPECTS OF BIOLOGY

1) All biological phenomena have two sets of causations, those controlled by the historically accumulated information of the genetic program (evolutionary or ultimate causations), and those controlled by the properties of the interacting system (proximate causations). The study of the historical components of each system is as legitimate a concern of biological science as the study of proximate causations.

2) Regularities in biological processes (above the molecular level) only rarely have the character of universal laws.

3) The outcome of biological processes is usually affected simultaneously by multiple causations, owing to the complexity of the systems interacting with complex biotic and physical environments.

4) Many properties of systems, such as higher levels of integration, cannot be explained by a study of their isolated components. The integration of systems results in the emergence of new properties because "the whole is [often] more than the sum of the parts." The emergence of new properties is characteristic of higher levels in any hierarchy of systems, even in inanimate ones.

Some of the differences between physics and biology are due to provincial aspects of biology, and others are due to provincial aspects of the physical sciences. This includes in particular three major philosophical principles that are characteristic of traditional mechanics, and reflected in the traditional philosophy of science (even though they are no longer as absolute in modern physics as they were when physics had its greatest influence on philosophy). I am referring to the principles of determinism, essentialism and reductionism.

Determinism is responsible for a belief in absolute prediction. The traditional physicalist hopes "to find a few simple laws" that would explain all of nature, and to translate all relationships into mathematical equations. Nothing is considered by a physicalist to be an exact science that does not have strict laws and unitary theories. It is well known that Kant claimed there was only as much genuine science ("eigentliche Wissenschaft") in any science as the amount of mathematics it contained. And Rosenberg (1985) considered physics the exemplar of science to such an extent that he thought biology had "the obligation to meet the kinds of standards demanded by physics" (p 28). The truth is, of course, that biology has to meet the standards of science, but it does not have to meet the provincial standards of *physical* science.

THE AUTONOMOUS FEATURES OF BIOLOGY

Even those authors, like Mainx and Ruse, who denied the autonomy of biology, admit (how could they do otherwise?) that it differs in numerous ways from the physical sciences. Yet they say that this difference is not "significant" because biology, as a science, has the same logical structure as the physical sciences, and is an empirical enterprise. Rosenberg (1985), after reporting that "autonomists and provincialists both agree that much biology differs from physics in irreconcilable ways" (p 25), nevertheless claims that "no irreconcilable differences have been enumerated so far" (p 26). In truth, they have been enumerated (see Mayr 1982:36-67), and I further expanded on this subject in 1985 (p 61) and 1988 (pp 14-21). Perhaps the most concise way to characterize the uniquely different nature of *organisms* is to describe them as *hierarchically organized systems, operating on the basis of historically acquired programs of information*, a definition that does not apply to any inert object.

ARGUMENTS OF ANTIAUTONOMISTS

Traditionally, the argument against an autonomy of biology was simple: Only Cartesian science (physicalism) is exact science, and only exact science is real science. Whatever in biology does not answer to the Cartesian concept has to be assigned to vitalism. Although this view has still been expressed rather recently (e.g., Crick 1966; Smart 1963), Nagel (1961) recognized perceptively that classical vitalism, such as that of Driesch, "is now almost entirely a dead issue in the philosophy of biology . . . [but that] many outstanding biologists who find no merit in vitalism are equally dubious about the validity of the Cartesian program and . . . advance . . . reasons for affirming the irreducibility of biology to physics, and the intrinsic autonomy of biological methods" (pp 428–429).

Organicism has little to do with vitalism, except for the thesis that organisms are not simply inert matter. In other words, physicalism and vitalism are not the only two possible philosophies of biology: Organicism is a third option. If one wants to reject the autonomy of biology, it is no longer sufficient just to refute vitalism. Now it is necessary to prove that it is possible to reduce organicism to the Cartesian program, and no one has been able to do this.

One finds in their rather extensive literature that reductionists usually adopt one of two strategies. They may say that "vital processes" can be reduced to physicochemical processes, which obey universal laws, and that anything in biology that cannot be reduced in this manner is simply not part of science. And since the reduced portion of biology obeys the Cartesian program, there is no reason to acknowledge an autonomy of biology. The other option is not very different. It simply designates the part of biology that cannot be expressed in the terms of universal laws as natural history, and claims that natural history is not part of science.

Proponents of both of these solutions are utterly unaware of the duality of causations for all biological phenomena and processes. All biological phenomena and processes are controlled both by proximate and by evolutionary causations. The biology of proximate causations can indeed, to a large extent, be reduced to chemistry and physics. Yet nothing in the realms of physics and chemistry is equivalent to the evolutionary causations that are controlled by the genetic programs of all organisms. Simply to ignore a major determinant of all biological processes is both bad science and bad philosophy.

Since inanimate matter does not have such programs, Cartesians attempt to escape their dilemma by labeling any reference to adaptedness and teleonomic processes as "teleological," and hence metaphysical and outside empirical science. As I have shown elsewhere in an analysis of teleology (Mayr 1992), adaptedness and teleonomic processes are legitimate empirical phenomena, based on strictly material processes, and therefore are valid components of science. To consider them metaphysical is the unfortunate result of equivocation. Philosophers of science, up to the present, have confounded four different sets of phenomena (Mayr 1974, 1992) by using the same word, "teleological," to refer to them.

The antiautonomists are peculiarly inconsistent in their attitude toward possible metaphysical aspects of biology. Nagel rejects certain aspects of biology because he considers them to be teleological, and therefore metaphysical. By contrast, Rosenberg (1985) rejects an autonomy of biology: ". . . because no appeal is made to a metaphysical difference to justify methodological and epistemological claims of autonomy, these claims are ungrounded and unexplained" (p 23).

We can summarize these arguments by saying that physicalists justify rejection of the autonomy of biology by simply concentrating on those aspects of biology that are found in any science and therefore automatically equivalent to aspects of physics; by completely ignoring all the uniquely characteristic aspects of biology, particularly the biology of evolutionary causations (including the existence of genetic programs); by failing to admit the emergence of novel properties in higher level hierarchical systems; and by using equivocal terms such as "teleological" and "reductionist."

After a long analysis which, on the whole, provides a remarkably objective statement of the claims of organicists, Nagel (1961) concludes "that organismic biologists have not established the absolute autonomy of biology" (p 444). Unfortunately, he nowhere explains what he means by "absolute autonomy." If one could plot the domains of the physical and biological sciences on a map, one would find a considerable area of overlap. This would include the area relating to science as such that is shared by both fields, and it would also include much of the molecular level, where the physicochemical processes are, in principle, the same in living organisms and in inanimate matter. The term "autonomy of biology" refers, however, to the irreconcilable differences between living beings and inert matter that are not included in the area of overlap. Since every organicist admits the existence of an area of overlap, he does not claim an "absolute" autonomy, and Nagel's argument turns out to be nothing but a straw man.

Several antiautonomists have expressed the fear that a recognition of the unique features of biology would "lead to epistemological and conceptual conclusions that are not contained in the laws of the physical sciences." It would seem obvious from the preceding discussions that such conclusions indeed are inevitable: they merely reflect the characteristics of nature, the provinciality of physics, and the incompleteness of the former philosophy of science.

Some of the quoted statements of opponents of the autonomy of biology are more than 25 years old. The evaluation of biology has been reshaped considerably since then, so it is quite possible that the authors no longer hold the views reflected by their earlier statements.

THE POSITION OF THE AUTONOMIST

Hardly any modern biologist questions my statement "that all organic processes can ultimately be reduced to or explained by physicochemical processes. None of the events and processes encountered in the world of living organisms is in any conflict with the physicochemical explanation at the level of atoms and molecules" (Mayr 1988:11). Nevertheless, there is no question "that much of biology differs from physics in irreconcilable ways" (Rosenberg 1985:25). One organismic biologist after another has pointed out in how many different ways the world of life differs from that of inanimate objects. In 1961, I called attention to the duality of organisms provided by their historically acquired genetic programs. In 1964, Simpson made a vigorous plea for the recognition of the fact that the laws and principles of the physical sciences are simply inadequate for the explanation of the phenomena of life. He stressed that biology—which accepts the principles of the physical sciences at the molecular level, yet in addition has developed the rich science of organismic biology—is a much broader, more comprehensive science than physics, and is able to explain a much greater part of nature (for counterarguments, see Shapere 1969).

A similar conclusion is also reached by Pantin (1968): He refers to the physical sciences as restricted sciences, and to the sciences of complex systems, such as biology, as unrestricted sciences (p 18). The relation between physics and biology is analogous to that between Euclidean and non-Euclidean geometry. The physical sciences are as restricted in their scope as is Euclidean geometry. Biology and other complex sciences are not limited by the constraints imposed by the laws of physics. Their domain is as expanded as that of non-Euclidean geometry. Even Rosenberg (1985), a philosopher rather sympathetic to reductionism, admits that the concepts and terms used in evolutionary biology, behavior, ecology, immunology, and genetics, reflect "notions utterly beyond assimilation by current physical science" (p 33).

The question of whether biology is a science exactly like physics and chemistry, governed by the same universal laws, must firmly be answered with a NO. It can no longer be denied that biology leads to epistemological and conceptual conclusions that are not contained in the laws of the physical sciences.

Those who for a long time have been trying to achieve a unification of science may well be rather dismayed by this conclusion. Actually, a unification of science is by no means made impossible by our new insights. As Simpson has stated so forcefully, however, that unification will have to be achieved not by making biology a province of physics (and by necessity excluding from biology everything that is not covered by the laws of physics), but rather by recognizing a broader field of science in which both physics and biology are provinces. Both physics and biology are sciences, but both are provincial in the sense that each has its own methodology, subject matter, laws and conceptual framework. Both are provinces of a larger, integrated science, within which both have a great deal of autonomy. Considering the large area of overlap represented by the general principles of science, however, it would be misleading to speak of an "absolute autonomy," as was done by Nagel.

Up to this point, I have compared physics and biology, because this is what has been done traditionally by the philosophers of science. Nonetheless, this is clearly an oversimplification. Indeed, it is rather misleading to ignore the heterogeneity of both biology and the physical sciences. Many of the laws of classical mechanics no longer hold in quantum mechanics, relativity theory, and elementary particle physics. Concepts such as probability, chance, time and several others that did not exist in classical mechanics are employed in these branches. Curiously, these are concepts that for a long time had already been important in biology. Yet biology is equally heterogeneous, particularly owing to its dual role as a biology of proximate and a biology of evolutionary causations. One consequence of this heterogeneity of both physics and biology is that the gap between the two sciences has become much smaller in recent years. This is due not only to the complete rooting out of the last remnants of vitalism and cosmic teleology from biology, and to the new physicochemical foundations laid by molecular biology, but perhaps even more so because the physical sciences have become less restrictive in their claims. Many of the assumptions and concepts, already standard in the biological sciences, have now also been incorporated in the physical sciences. The gap between these sciences has thus been narrowed in a number of ways.

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