# The Ideological Resistance to Darwin's Theory of Natural Selection*

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There has been a longstanding controversy in scientific historiography whether new ideas and concepts owe more to "internal" causation (i.e. advances and discoveries within science) or "external" causation (i.e. prevailing ideologies and/or the socioeconomic situation of the period). Without taking sides on this issue (but see Mayr 1982:5), I want to take a closer look at the "external" factors, and particularly the role of the "Zeitgeist" (prevailing ideologies). The standard view of the externalists is that the nature of the ruling ideas determines, or at least strongly influences, the nature of new conceptual innovations in science. This may well be correct in some instances, but there is far more evidence for an inhibiting rather than an innovative influence of the Zeitgeist. I will attempt to document this by the example of Darwin's theory of natural selection.

One of the most interesting phenomena in the history of ideas is the vigor with which new discoveries or theories are often opposed. The Church, the government, or other institutions outside of science are often held responsible for such resistance. Actually, as has been convincingly demonstrated by Barber (1961), it is usually the scientific peers who are the source of the strongest resistance.

The time which passes until a new discovery or theory is accepted by science varies greatly. In the case of the discovery of a new fact, as in the elucidation of the structure of DNA through Watson and Crick, a new discovery is sometimes accepted at once. However, it usually takes scores of years before a conceptual revolution can establish itself. Newton's theory that gravitation is responsible for the movement of the planets required some 60 to 80 years until it was universally adopted. Even though Alfred Wegener's theory of continental drift was published in 1912, it was not accepted until more than 50 years later, after the theory

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of plate tectonics had been proposed. Mendel's theory of inheritance required 34 years before it was accepted. However, I do not know of another scientific theory that had to wait as long to be accepted by the leaders of its discipline as Darwin's theory of natural selection. In order not to be misunderstood I want to emphasize that among Darwin's five major theories of evolution (Mayr 1982:505–510) I am singling out only one, the theory of natural selection. To be sure, some of Darwin's other theories were at first also vigorously resisted, because they questioned broadly accepted views of the time, such as the Biblical chronology, the constancy of the world, and the special position of man in nature. However, these three theses were abandoned already during Darwin's lifetime. The resistance which natural selection encountered was however much wider and more vehement, indeed more so than perhaps any other valid theory in the history of science. During the first 60 years after its publication in 1859, natural selection was accepted virtually only by naturalists. I do not know of a single experimental biologist prior to 1920 who was a consistent selectionist. It was not until the 1940s, that is, 80 years after the publication of the *Origin*, that the so-called modern Synthesis, was formulated owing to which the majority of biologists agreed that selection was the only direction-giving factor in evolution, that is, the only factor that could account for adaptation (Mayr and Provine 1980). Among nonbiologists, particularly in the nonanglophone countries, natural selection is still widely resisted. It would be an error to believe that theology or the Church had been responsible for this resistance; that this is not the case has been demonstrated convincingly by Gillespie (1979), Moore (1979) and other historians. No, the resistance had a much broader basis.

The question we must ask ourselves is why this particular scientific revolution encountered so much more resistance than any other. My conclusion is as follows: all other scientific revolutions, perhaps with the exception of Freud's discovery of the subconscious, were either rather specialized technicalities or did not require any correction in the worldview of the average person. The scientific explanation of the movement of the planets by Newton or Einstein's theory of relativity do not have any conceivable influence on the life philosophy of Mr. Smith or Mrs. Murphy. The same is true for quantum mechanics or the question whether the nature of light is corpuscular or consists of waves. These purely physical theories have no relation to any basic worldviews of the individual. That there are such basic worldviews, and how important they are for a given historical period, have been well demonstrated by the researches of the historians of ideas. In the present investigation I will concentrate on a series of universally held ideas which, at the time of the publication of the *Origin of Species*, were quite generally considered to be true. One must realize that some of these ideas were so much taken for granted that quite often they were not even conscious to their adherents. These are the subconscious but totally dominating basic ideologies of an era.

Darwin's theory of natural selection was in conflict not just with one but actually with at least five of the ideas that were universally accepted at the middle of the last century. The adherents to these ideas felt attacked by Darwin and defended themselves energetically. The argument in most cases did not concern the validity of the facts used by Darwin to support his theories but with their interpretation, and in this respect certain ideologies had a decisive influence, even though their basic sphere of relevance was outside of science.

Who were these opponents of natural selection? In the first place we must mention the physico-theologians, for whom the harmony of the world created by God and supplied by him with laws, was the best proof for the existence of God. Almost all of Darwin's teachers and colleagues in England were natural theologians.

A second group of opponents were the teleologists from the Greeks to Kant and K. E. von Baer, who were firmly convinced that the world was driven by some intrinsic force or some law of nature or directly by the hand of God, which would lead it to ever-greater harmony and perfection.

A particularly formidable impediment of the selection theory was the fact that most philosophers of the last century were essentialists in the sense of Pythagoras and Plato.

Finally, Darwinism was in conflict with the basic principles of the theory of science which since Galileo, Descartes and Newton had been derived from physics, mathematics, and logic.

The situation was aggravated by Darwin's adoption of the theory of common descent through which the position of man in nature was totally altered. To be sure, this thesis of Darwin's had no immediate relation to natural selection, but it certainly contributed to the anti-Darwinian sentiment of the period.

Today, 130 years later, we realize that Darwin through his many entirely new ideas had become the founder of a totally new philosophy. It was a philosophy which differed so fundamentally from the existing philosophies that the philosophers of the nineteenth century did not even notice that Darwin's teachings represented a philosophy. Almost unanimously they repeated again and again, "Darwin was no philosopher," indeed, they insisted that he did not understand philosophy.

## The Basics of the Selection Theory

In order to be able to document in what respect Darwin's theory was in conflict with particular ideologies, it is necessary to describe Darwin's theories in a few words.

1) Species of animals and plants consist of populations which, from generation to generation, maintain approximately the same size. In spite of the fact that each pair of parents produces hundreds, thousands, or even millions of offspring, on the average, always only two of these will make a contribution to the next generation.

2) Genetic variation in nature is so inexhaustible that there are never two individuals that are completely identical and equally well adapted to the momentary environmental constellation.
3) Those that are best adapted have the greatest probability to survive, to reproduce, and to transmit their attributes to the next generation.
4) In this manner, populations can continuously adjust to the changes in their environments; and it is this which explains the never-ending diversity of adaptations of animals and plants to each other and to inanimate nature.

Why and how are these basic aspects of natural selection in conflict with the mentioned ideologies dominant at that period?

## Natural Theology

They were of course in every respect in conflict with natural theology, which dominated the thinking of natural scientists until the 1860s. The rise of science in the seventeenth and eighteenth centuries led to an intensive occupation with all aspects of nature, that is, with the work of God. In particular, there were two features of nature which seemed to prove the existence of a creator, one being the marvelous adaptations of all animals and plants to each other and to inanimate nature, while the other were the laws of nature, which regulated all processes in nature so beautifully.

Further evidence for the hand of God was discovered in the eighteenth and the first half of the nineteenth centuries, in the hierarchical order of the types of animals and plants. This led to the foundation of comparative morphology by Goethe and to the establishment of a system of animal types by Cuvier, von Baer, Oken and Owen. As was emphasized by Louis Agassiz again and again, such an order in nature was inexplicable unless ascribed to the hand of the Creator. Natural theology was particularly strong in England; yet on the continent where the naive natural theology of the eighteenth century was no longer accepted, arguments ultimately resting on natural theology were still widely used in Darwin's time.

All this was now questioned by Darwinism. The system of archetypes from Goethe to Owen, which only described but not explained, was replaced by the theory of common descent. At the same time it seemed that natural selection made it unnecessary to postulate the activity of a Creator responsible for all the miraculous adaptations. Not surprisingly the new explanations generated an enormous resistance.

## The Influence of Essentialism

A further ideology, which impeded the acceptance of natural selection was essentialism. With this term we designate a mode of thinking which was derived from the geometric thinking of Pythagoras and Plato (Mayr 1982). Behind all variable phenomena of nature lies, according to essen-

tialism, an invariant essence. For example, a triangle, regardless of the combination of its angles, always has the form of a triangle, and is therefore discontinuously different from a rectangle or any other kind of polygon. Plato interprets analogously the variable world of phenomena as the reflection of a limited number of constant forms, *eide* (as he called them) or essences, as they were called by the Thomists in the Middle Ages. These essences are the only thing in this world that are real and important, and as ideas they exist independently of all objects. Special weight was placed by essentialism on constancy and discontinuity among essences. Variation represents simply imperfect manifestations of the underlying essence. Since the essentialists denied any role to variation in nature, they simply had to reject the theory of natural selection, which is based so completely on variation. Essentialistic thinking is frequently also referred to as typological thinking. This way of thinking was at least on the European continent dominant in Darwin's time. Whether a philosopher called himself realist or idealist, materialist or nominalist, as far as biology was concerned, all of them were essentialists. Species for them could be defined by constant characters and were classes that were separated from each other by discontinuities that could not be bridged in any manner. Darwin, by contrast, introduced an entirely new way of thinking, when he maintained that species are not classes but variable populations composed of uniquely different individuals. One can almost say that this view is an upside down version of the axioms of essentialism. For Darwin the real thing in nature was the uniqueness of the individual, while the mean value of the population was only an abstraction. For the essentialist on the other hand, the idea was the only thing that was real, and variation simply an "error" or "accident."

An evolutionary biologist is astonished to what extent essentialism still dominates the thinking of so many. To think in terms of populations has become universal, even in evolutionary biology, only in the last 50 years. Typological thinking is still widespread in many other branches of biology.

How can one explain this power of essentialism? First, because it applies excellently not only in most branches of mathematics but also in classical physics. Essentialism furthermore has a semantic-linguistic foundation. We have a kind of ideal picture for all designations which we use in our daily language, whether it is mountain, water, cow, or courage, and it is this idealized concept which is the basis of communication in our conversations.

The reason why essentialistic thinking is so strongly rooted in philosophy is because logic plays such a large role in the philosophical methodology. And as is shown in the well known examples of the paradoxes, there is no other way to proceed in logic but typologically. One only has to think of the embarrassment of the logicians when it was discovered that there are also black swans (in Australia) and partially white ravens (in Ethiopia).

I do not question that habitually we tend to think typologically and

that we become conscious of the uniqueness of phenomena only when we consider them more intimately. Then we discover suddenly how misleading it is when we speak *of the Prussian, the Jew, the Black, or the intellectual*. Each human being is unique, there is no second one alike to him. It was Darwin's genius to recognize that the same is true for animals and plants. With them also, so far as they are reproducing sexually, every individual is unique and different from all conspecifics. In a drought period 98 of 100 individuals of a species of plants may perish. But two others may have the needed physiological mechanisms to cope with the drought.

What Darwin taught us was to see the species not as a type but as a variable population in which the variability is renewed by sexual reproduction in every generation. This insight has two enormously important consequences for the understanding of evolution: first, it makes natural selection possible because each individual is an independent target of selection; and second, it explains why evolutionary changes, including the origin of new species, must be gradual, not requiring any saltations. Types, by contrast, can change only saltationally, that is, through the production of an individual which represents a new type. A population, however, changes by a slow shift of its mean value.

Darwin's *Origin of Species* was published on 24 November 1859. In the two or three years after publication more than 100 critical reviews of this work were published. How firmly essentialism was established at that time is made evident by the fact that among all these critics only about five had been able to emancipate from essentialism. All the others agreed that a transition from one species to another was impossible. To abandon the constancy of species would undermine the syllogisms of logic. Species, said Mill, are classes, which are separated from each other by an unbridgeable gap (Hull 1973).

How could the enormous power of essentialism be broken? How could this new way of thinking, to which I refer to as population thinking, prevail? And how did Darwin himself arrive at this new way of thinking? This is a most interesting historical problem, which has been analyzed only insufficiently up to now. This much is clear: essentialism was far less potent in England than on the Continent. The geologists Hutton and Lyell, as well as Darwin's grandfather Erasmus Darwin, were already dedicated gradualists. One also finds beginnings of population thinking in the writings of John Locke and of the so-called Scottish school (Adam Smith, Adam Ferguson, and Dugald Stewart), and the uniqueness of the individual had been consistently emphasized in the British school of animal breeders.

The defeat of essentialism was greatly helped by the development of the new concept of the biological species, which is based on population thinking. Also, the school of the young philosophers, which studies the concepts of modern biology intensively, has greatly helped to spread population thinking also in philosophy.

## A Teleological or Finalistic View of the World

A third ideology that opposed Darwinism was the teleological *Weltanschauung*. It was already known to the Greek philosophers and physicians that many processes in nature seemed to be goal-directed. The development of an individual from the fertilized egg to the adult stage was the example quoted most often, particularly in the work of Aristotle. Furthermore, that everything in nature and its processes had a purpose, a predetermined goal, was a widespread belief. The proponents of this conviction saw their belief confirmed not only by the *scala naturae* but also by the unity and harmony of nature in its manifold adaptations. The opponents of such a belief in teleology, the pure mechanists, were a small minority in the seventeenth and eighteenth centuries and indeed, until 1859. The teleological worldview acquired additional significance when one began to realize in the eighteenth century that the world had not been created only 6,000 years ago and as something altogether complete, but that it had gradually evolved. The deists explained this by saying that God had not only created the world but had also endowed it with laws, which regulate everything that proceeds in the world. And these laws would lead the world to ever-greater perfection.

Nowhere else did the concept of teleology have a stronger support than in Germany, from Leibniz to Herder and Kant. Kant was a strict mechanist as far as inanimate nature was concerned. However, he ascribed teleological forces to all phenomena of life. I am sure we all agree in our admiration for Kant. He was one of the few greatest minds in the history of mankind. I particularly admire how successful Kant was, in spite of his isolation in Königsberg, to keep up with the advances of science. However, his familiarity with the work of Buffon, Haller, Wolff, and Blumenbach could take him only as far as these authors had gone. Biology, at the time Kant wrote his *Critique of Judgment* (1790) and his *Opus postumum*, was still a terra incognita, except for the solution of some problems of physiology and a rather primitive systematics and anatomy. The birth of scientific biology occurred in the period of 1828 to 1865, and is denoted by the names Karl Ernst von Baer, Schwann and Schleiden, Liebig, Claude Bernard, Virchow, Darwin, and Mendel.

If in our day a philosopher would attempt to refute Darwin with the help of Kant's teleology, so would this be no less of an anachronism than if someone would reject Einstein, Niels Bohr or Heisenberg because their theories contradict those of Galileo and Newton. Since the state of biology made it impossible in Kant's time to explain the riddles of living nature, and since Kant did not want to exclude the phenomena of life from his grand edifice of the philosophy of science, he accepted provisionally a teleological explanation. This was at that time perhaps the only possible solution; it is a solution which today is no longer available.

Unfortunately there is still considerable confusion in the philosophical and also the biological literature as to the meaning of the concept

"teleological." The greatest error that is made again and again consists of a failure to analyze the relation between the putatively goal-directed object and its goal. In all seemingly end-directed processes in nature, one must always ask whether it is legitimate to ask the question why, in the sense of what for?

For instance, when one observes that a marine turtle swims for weeks from the middle of the Atlantic to the coast of Central America and undertakes such a migration annually at a certain season, one is unquestionably justified to ask why does she do that? Or, more directly: What for? We now know that such an animal is genetically programmed to undertake this migration, in order to lay her eggs in the sandy beaches. Both the migration as well as its goal are programmed in the annual cycle of the animal.

Let us take another example: within a few minutes 30,000 people are killed by a volcanic eruption on a densely populated tropical island. Five hundred years ago the question "What for?" was usually asked in such a case, and the answer that was often given was that this was God's punishment for the sins of this population. There are presumably only a few people left today who would be satisfied with this answer, indeed who would even ask the question "What for?" in such an instance. Who would believe in our times that it would be the purpose of a volcanic eruption to kill 30,000 people?

These two examples show us why the modern philosopher sorts all seemingly end-directed phenomena into several classes. A modern analysis has revealed that four very different processes of nature had been designated in the past with the same term teleological (Mayr 1976). It would be futile to attempt to clarify the concept of teleology as long as one fails to discriminate among these four seemingly end-directed processes. I have elsewhere presented a detailed analysis, and will mention here only what is necessary to understand why a teleological worldview was so completely opposed to an acceptance of natural selection.

First, there are natural processes that do have an end point: this, however, is strictly determined by a natural law. The fall of a stone owing to gravity or the cooling of a hot object, according to the first law of thermodynamics are examples of such processes. Since the end point in these cases is reached automatically, I call such processes *teleomatic.* All seemingly end-directed processes in inanimate nature, such as one can observe during the eruption of a volcano, or a change of weather or as takes place in galaxies, are determined by such natural laws. Aristotle has quite clearly described this category and has called such processes as "caused by necessity" (Gotthelf 1976).

A second category is represented by all those phenomena that are controlled by a genetic program such as the annual migration of marine turtles or the development of an individual from the fertilized egg to adulthood. These goal-directed processes in living organisms are referred to as *teleonomic,* according to Pittendrigh's proposal. Many nonbiologists have considerable difficulties in understanding teleonomic pro-

cesses because equivalent programs do not exist in inanimate nature. However, to deny their existence in living organisms is no longer possible after the great discoveries of the recent 30 years. Molecular biology has succeeded in tracing many teleonomic processes in ontogeny as well as in behavior to the molecules responsible for them. As Delbrück (1971) has shown, Aristotle already had understood the nature of teleonomic programs, and this has been confirmed by the philologists (Gotthelf 1976) who have analyzed Aristotle's writings.

The third category of teleological phenomena comprises what Kant had designated as *zweckmässig* and what the modern evolutionist calls adaptations or adapted systems. This includes also "purposely" functioning organs as the heart, stomach, kidneys, brain, etc. These are stationary systems, even though they have the capacity to control teleonomic processes. It was particularly this adaptedness which posed an unsolvable riddle for Kant in the period prior to a theory of evolution. Today it is in most cases possible to trace back in evolution to a single cell even highly complex adaptations, such as the eye.

A fourth category of phenomena that have been designated as teleological is cosmic teleology, that is, the belief that the world has an immanent capacity which will lead it to an ultimate goal or at least to ever-greater perfection. In contrast to the three previously mentioned forms of teleology, there is no evidence whatsoever for the existence of a cosmic teleology. Cosmic teleology must be rejected by science, because no natural laws have been found which could implement it, nor anywhere a program that could control such a teleology. I do not think there is a modern scientist left who still believes in it.

The often asked question whether goal-directed processes occur in nature can now be answered comprehensively. Two of the currently accepted "teleologies" can indeed be goal-directed: teleonomy, on the basis of an underlying genetic or learned program, and teleomatic, a consequence of the action of natural laws. The third category, organic adaptedness, is not directed toward an end but rather an adaptation to the environment in the widest sense of the word, acquired during evolution, largely guided by natural selection. The fourth teleology, the cosmic one, is not supported by scientific evidence.

Darwin had solved Kant's great riddle: who did not dare "to hope that someday a Newton will appear who will make understandable the production of a blade of grass according to natural laws without invoking purpose." Of course, even today, we cannot reduce biological evolution to purely physical laws, as they were known to Kant. Darwin's theory of natural selection has provided us with an explanation that does not have to use metaphysics or supernatural forces.

I might make the short historical observation that the modern analysis of teleological phenomena has contributed considerably to a clarification of Aristotle's concept of teleology. Gotthelf, Nussbaum, Balme, and other Aristotle specialists, agree that Aristotle accepted teleonomic and teleomatic causes but by no means believed in a cosmic teleology. As in

so many other things, Aristotle was remarkably modern even on this subject.

A deep conflict existed from the era of Greek philosophy to the middle of the last century, between a teleological and a purely causal-mechanical explanation of the world. Sometimes one, sometimes the other concept of the world seemed victorious. Or one could proceed, as was done by Kant, and be a causal mechanist with reference to inanimate nature, and a teleologist with reference to the world of life. One of the reasons why Darwin was so heavily attacked after the publication of the *Origin* was that the selection theory made a belief in a cosmic teleology unnecessary. It was a belief in teleology which induced Karl Ernst von Baer and several other of Darwin's contemporaries to attack the selection theory so temperamentally. Indeed, a belief in an immanent driving force in nature was so deeply embedded in the thinking of the period that during the first eight decades after 1859 there were more evolutionary teleologists than adherents of natural selection. Eimer's orthogenesis, Osborn's aristogenesis, Berg's nomogenesis, and Teilhard de Chardin's omega principle were all based on the belief in a cosmic driving force (Bowler 1983). The invalidity of all these theories has been demonstrated so convincingly during the last 50 years that there is not a single representative of a teleological theory of evolution among living well qualified evolutionists. If a biologist occasionally uses teleologically sounding formulations of terminologies, as for instance if he says a plant had adapted itself to the conditions of desert life, then this is nothing but a convenient shorthand for a strictly selectively occurring sequence of events. As Max Delbrück has emphasized so rightly, all teleonomic and adaptational phenomena have a history. Therefore they cannot be directly explained by causal mechanical forces, as are processes in inanimate nature. I will come back to the revolutionary significance of this new insight in a later section.

## Aspects of Natural Selection

This is not the place to present a detailed analysis of the concept and the workings of natural selection. This has been excellently done by several authors in recent years (Futuyma 1986, Sober 1984, Endler 1986). However, it might be helpful to call attention to some aspects of natural selection that are frequently overlooked.

It has become evident in recent years that selection is a two-step process. The first step in every generation consists of the production of an immense amount of genetic variation (every individual is genetically unique) while the second step is selection *sensu stricto.* There is really nothing puzzling about this second step. It is perfectly obvious that in any given situation those individuals that are physiologically or behaviorally best adapted have a higher probability of survival than other individuals of the population. Which of the thousands or millions of the offspring of a set of parents will be the survivors cannot be predicted at the time of birth. Circumstances and a certain amount of luck are respon-

sible for a few individuals being left to produce the next generation. Two aspects of the genetic variation must be specially mentioned. The first is that it never is produced in order to fill a need of the population or species. Second, it is largely a matter of chance. Every single step that precedes the production of an egg or spermatozoan is a chance event.

Sewall Wright, François Jacob and other evolutionists have pointed out that selection, owing to its two-step nature, combines chance and necessity in a unique manner. At the first step, the production of genetic variation, chance predominates. At the next step, the survival of individuals of the next generation, chance plays only a minor role, and the survival depends largely on the adaptedness of the individuals exposed to selection.

Darwin never questioned that the individual as a whole was the target of selection. Later, under the reductionist influence of the mathematical population geneticists, one tended for a while to consider the gene as the target of selection, and to define evolution as a change in gene frequencies in populations. We have now returned again to Darwin's position, to consider the individual the real target of selection, because it is always an individual that is successful or not in the struggle for survival and in reproduction.

Darwin was way ahead of his time also in recognizing that there are two kinds of selection, which he called natural selection and sexual selection. Natural selection concerns everything that enhances the chance for survival, such as a better utilization of resources, better adaptation to weather and climate, better resistance to diseases, and a greater ability to thwart enemies. Sexual selection concerns everything that increases reproductive success, whether this is the resplendent plumage of a peacock or male bird of paradise, or the giant size of an elephant seal bull. Ever since some 25 years ago one has become aware of the importance of selection for reproductive success, one has discovered a large number of behavioral mechanisms which have no influence on the survival of an individual but contribute toward an increased number of descendants. In the work of Trivers, Hamilton, Alexander, Maynard Smith, Dawkins and other biologists, dozens of such mechanisms have been discovered.

## The Role of Chance

The assumption that chance plays such an important role during the first step of selection, the production of variability, was not acceptable for most of Darwin's contemporaries. As strict determinists they believed that everything in nature was controlled by necessity. Ignoring the second step of selection, they referred to the theory of selection as a theory of accidents. How an accident can produce such a perfect organ as the eye was a frequently heard objection. Those who asked this question ignored that chance plays only a subordinate role in the second step. Admittedly the success of the best adapted is only probabilistic because even at the second step chance enters the proceedings quite regularly.

It is now obvious that the very aspects of selection that were anti-teleological, such as the two-step nature of selection, and the interaction of chance and the direction-giving factor of selection, were responsible for the unpopularity of selection.

## Darwin's New Philosophy of Science

Ever since the publication of the *Origin of Species* it has been claimed that Darwin had not been a philosopher. Indeed, Popper has given a regular caricature of Darwin's philosophy (Ruse 1981). Lakatos went to the extreme of calling Darwin a "lousy philosopher," and Darwin is hardly mentioned in the about ten most important works on the philosophy of science published during the past 20 years, and if mentioned, only in a deprecatory manner. What can be the cause of this evaluation?

A picture of science has developed since the Renaissance, or perhaps more precisely since the seventeenth century that was formed entirely by mathematics and physics. Philosophers from Bacon and Descartes to Locke and Kant were of the same opinion as the physical scientists from Galileo and Newton to Lavoisier and Laplace, that it should be the ideal of science to propose mathematically formulated theories that are based on universal laws. Proof and the capacity for exact prediction were considered the yardsticks for the quality of a scientific explanation. Essentialism and determinism were the bases of this philosophy. The dimension of time did not occur in the laws of mechanics.

Darwinism occupied an almost diametrically opposed point of view on all these issues. It rejected both essentialism and determinism. Predictions could only be probabilistic-statistical. Explanations always took historical circumstances based on observation into consideration. All this was to such an extent alien to the physical scientists of the nineteenth century that for instance John Herschel referred to natural selection contemptuously as a theory of "the higgledy-piggledy," while Rutherford referred to natural history as a kind of postage stamp collecting. To attribute scientific status to the selection theory was not acceptable to them. Curiously the philosophers of the nineteenth century, as well as many philosophers up to the present day, did not realize that Darwin had become the founder of a new philosophy, a philosophy of science that is fundamentally different from any earlier one.

Interestingly, much that was unacceptable to the physical scientists in 1859 is in the meantime accepted by modern physics. The biologist Darwin simply was way ahead of his time. To describe in detail and to justify what Darwin's innovations were would have to be the subject for a major dissertation. I shall try to characterize them in a few short paragraphs. In addition to the rejection of physico-theology, teleology, and essentialism, Darwin's philosophy is characterized by the following eight aspects.

1) *Incorporation of history in the theory of science.* By the middle of the nineteenth century there was no longer any doubt among cosmologists

and geologists that the world had a history. This curiously had hardly any effect on the philosophers. For them a philosophy of history was of relevance only for man. It was Darwin who quite emphatically introduced the historical component into the science of living nature. Every species, and hence also every individual was a product of history. And every individual carried with him in his genetic program the experiences of three and a half billion years of its evolutionary history as Delbrück (1949) expressed it.

The theoreticians of science prior to 1859 were unable to incorporate history into the physical sciences. One could not experiment with it, and one could reconstruct it only by indirect inference. How could this be reconciled with the objectivity of science? There was no room for history in the classical philosophy of science from the Vienna positivists to Hempel-Oppenheim and Nagel. And this was even true for Karl Popper until the end of the 1970s. There can be no doubt, as was shown by Ghiselin (1969), Mayr (1982), and Gould (1986), that Darwin had founded a new methodology, the methodology of the historical sciences.

The acceptance of such a methodology created great difficulties for theoreticians coming from the physical sciences. Delbrück described some years ago how difficult it was for him as a physicist to comprehend the historicity of living organisms.

It is of no relevance for the properties of an atom or elementary particle whether it is only a few thousand or many billions of years old; they are all the same. An organism, by contrast, is what its genetic program prescribes, and this genetic program has a history of billions of years. The existence of this program is the fundamental difference between the inanimate and the living world. This was seen by the physicist Boltzmann already in Darwin's time. Most of the physicists and philosophers, however, resisted this new insight and were forced, in order to be consistent, to deny the validity of Darwinian thinking.

2) *The two biologies.* The duality of each living being, due to the fact that it consists of a genetic program, as well as of a body produced and controlled by this program, has the consequence that we must recognize two branches of biology: the biology of the body, that is, the biology of all proximate or physiological causations, and the biology of genetic programs, that is, the biology of evolutionary causations.

How do these two biologies differ? The biology of proximate causations deal with all the functions of the organism, including its embryonic development. Or, to formulate it somewhat differently, it is preoccupied with the translation of the genotype into the phenotype and with the activities of the phenotype. Almost anything that occurs in this realm can be reduced to purely chemical-physical processes (Mayr 1961).

The domain of the biology of evolutionary causations is quite different. The question here is "why?"; and this can be answered only historically. The concern of this field can also be expressed in the question "How did the genetic program for this structure or for that adaptation originate?" It was Darwin's great achievement not to have invoked

supernatural forces as customary at his time, but to have developed a causal mechanical model, the selection theory. Even if Darwin's theory had been altogether wrong (which it was not), it would nevertheless have been the first endeavor to incorporate the biology of evolutionary causations into science. With Darwin's new model, all earlier attempts to explain evolutionary phenomena as the effect of supernatural forces had become an anachronism. It has become clear through Darwin why telonomic programs as well as all phenomena of adaptation can be explained only historically and not directly causal-mechanically. The explanatory methodology of the two kinds of causations is very different. The classical methodology, as developed by the physical sciences, is quite suitable for the phenomema of proximate causation (for instance for physiological processes). By contrast the causation of a historical process can be made probable only indirectly by inference. In his explanations Darwin asked again and again "How else could this be explained except by descent guided by natural selection?" Such an explanation was quite unacceptable for the philosopher of science of his period.

3) *Determinism.* We are all familiar with Laplace's daring claim that if he knew all aspects of the current situation he would be able to predict the future for all time. This was only an extreme version of the widespread conviction of the classical philosophers of science that determinism and strict predictability were inseparable attributes of a scientific theory. Darwin rejected both of these postulates as criteria of the scientific quality of a theory. In his rejection of straight determinism Darwin was half a century ahead of the later developments in physics.

4) *The role of chance.* As we saw already during the discussion of natural selection, chance played an important role in Darwin's theorizing. The world is affected to such an extent by stochastic processes that in many and perhaps all evolutionary processes one can only operate by postulating probabilities.

5) *Simultaneous causation.* Every process was dealt with separately in the classical philosophy of science, in order to permit an independent study of its direct causation. This is of course the ideal of a scientific analysis even today. In many evolutionary processes, but also in ecology and many other areas of biology, it is often impossible to separate various causal factors from each other. In natural selection, for instance, variation and selection as such are nearly always taking place simultaneously. Chance phenomena can almost never be cleanly discriminated from directed processes. Wherever we look we encounter multiple causations and it is in many cases quite impossible to make a numerical determination of the individual factors, particularly because each factor usually depends on the relative magnitude of other simultaneously acting factors.

6) *Uniqueness in biological systems.* Inanimate nature is characterized by the existence of large classes of identical objects. Each sodium atom is like any other, and this is equally true for all classes of atoms and ele-

mentary particles. Exactly the opposite is found in living nature. No two individuals in sexually reproducing species are identical with each other, perhaps not even two cells in an individual. And of course even larger systems, like species, animal societies, ecosystems, faunas and floras, are completely unique. Generalizations which one can abstract from such uniqueness are fundamentally different from the universal laws which one can derive from classes of identical objects, such as the ones with which a physicist has to do.

7) *An expanded methodology.* The classical philosophy of science recognized only one method, the experiment. Now we realize that experiments are impossible in many branches of science. In such a case one must make use of other methods, particularly of observation and comparison, which are the most frequently used methods, not only in evolutionary biology but also in geology, meteorology, oceanography and cosmology. It is curious that even today there are text books of philosophy of science in which it is stated that the experiment is the only legitimate method of science.

8) *A new language of science.* When Darwin published the *Origin of Species* no terminology was available for the new philosophy of science which he developed. The technical terms which he introduced were unfamiliar to his peers, and since they had usually been taken from the daily life they had other connotations that were much better known than the aspects which Darwin wanted to express. The term *selection* for what is really a result, an *a posteriori* phenomenon, is one example. The species, to be conceived as a population rather than as a type, is another one. Darwin's terminology of the evolutionary phenomena was another reason why there was so much resistance to his theories (Manier 1978).

## Conclusion

I hope I have succeeded in demonstrating how many factors played a role in preventing an immediate acceptance of Darwin's theory of selection. Darwin's new philosophy of science was largely ignored by philosophers for more than 100 years. It is only in the last two or three decades that a new generation of philosophers has realized that what was correct for classical mechanics is not at all characteristic of science as such and as a whole, indeed, not even for the natural sciences. In order to characterize the nature of science comprehensively one must vigorously expand the narrow framework that had been constructed by the philosophers and scientists of the seventeenth and eighteenth centuries. It is in this direction that many of the younger philosophers of science work. An inevitable consequence will be a further weakening of the ideologies which even today prevent the acceptance of the theory of selection in certain philosophical circles. They will be replaced by ideas developed by Darwin and evolutionary biology.

What is perhaps the most important conclusion taught us by the fate

of Darwin's theory? It is that every single one among us should review the ideologies to which he subscribes and to root out those ideologies from his *Weltanschauung*, even though they are accepted as self-evident by everybody—as were formerly teleology, essentialism and determinism—that are nevertheless untenable. Thus Darwinism challenges not only science and philosophy but every thinking human being. This personal challenge is part of the heritage which Darwin has left us.

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