statement of the effect of temperature on the maintenance requirement of biological structure. The book's central concept is then introduced in the final chapter with an order function, $L = \Delta A/(kT/h)$, the ratio of Helmholtz free energy (ΔA) of the biological structure to the temperature-dependent disordering flux that must continually be overcome if that structure is to be held at steady state. Morowitz's order function is similar (reciprocal) to a quantity which I have called the Schrödinger ratio (*Pollution and Marine Ecology*, T. A. Olson and F. J. Burgess, Eds., p. 135) and which is identical with the very old empirical variable in ecological measurement, respiration-to-biomass (turnover) ratio. Morowitz uses Helmholtz free energy, whereas most biologists use Gibbs free energy and thus sweep pressure-volume changes under the rug. At the end he does some elegant manipulations showing, for example, that as temperature rises the difference in behavior of numerator and denominator causes the order function to pass through a maximum. Following Margalef he believes that nature maximizes the ratio of structure to maintenance metabolism. In this he is probably wrong, because he ignores the role of natural selection by which energy flow is maximized instead, so that sometimes high biomass is produced and sometimes low, depending on programs for adaptation to temporary irregularities in input energies.

This book's elaboration of the Schrödinger theme and related functions will irritate many biologists because old concepts are generated *de novo*, as if new, whereas what is new is putting them in the language of the molecular physicist. This Yale professor was trained in a setting in which the ideas of A. J. Lotka were influential. Without citation of Lotka's writings or of others in the literature he now writes the same story of the self-correcting homeostasis of the closed mineral cycle, general reaction kinetics of light on a cycling receptor system, and other well-established principles of systems ecology.

As the diversity of scientific schools of thinking and scientific languages increases, it may be increasingly frequent that synthesizers will use the notation of one field to generate theory concerning the material of another without mastering the literature of the latter and without realizing that the theorems are as clearly established in other forms. If it is quicker for a keen mind to generate knowledge anew than to be responsible for the huge literature of other fields, what is his obligation? A real difficulty may be the Ptolemaic arrogance with which those working at one level of integration tend to regard a theory as unproven until it is stated in the notation of their own discipline. This is a pitfall for students of the small who undertake to deal with the large, mainly because education for the small often omits the large as if it didn't exist.

In any case, ecologists and biologists will be fascinated to find their familiar concepts restated in the (to them) more cumbersome molecular formulations which they must now master. The book will help their colleagues in physics to discover complex open systems and will show biologists who among the molecular contributors to unfamiliar journals have written papers pertinent to the old problem of order.

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Evolution by Orderly Law

Der gerechtfertigte Haeckel. Einblicke in seine Schriften aus Anlass des Erscheinens seines Hauptwerkes "Generelle Morphologie der Organismen" vor 100 Jahren. GERHARD HEBERER, Ed. Fischer, Stuttgart, 1968 (U.S. distributor, Abel, Portland, Ore.). xii + 588 pp., illus. $19.50.

Nomogenesis, or Evolution Determined by Law. LEO S. BERG. Translated from the Russian edition (1922) by J. N. Rostovtsov. M.I.T. Press, Cambridge, Mass., 1969. xxiv + 488 pp., illus. Paper, $3.95. Reprint, with a new foreword by Theodosius Dobzhansky, of the 1926 edition.

To review either the volume of selections from Haeckel's *Generelle Morphologie* or the reprinted translation of Berg's *Nomogenesis* would be interesting in itself, but the opportunity to review both permits a most fascinating comparison, for these books, extremely different in many ways, are yet so similar. Haeckel's *Generelle Morphologie*, published in the decade following Darwin's *Origin of Species*, was one of the most influential evolutionary treatises ever written. Haeckel was committed to the spread of the Darwinian view of evolution and to the discovery of basic evolutionary mechanisms; indeed, he was one of the few workers in the 50 years following Darwin who considered the problem of evolutionary mechanisms rather than merely constructing phylogenies (a word coined by Haeckel). His basic concept—the famous Biogenetic Law—that "ontogeny recapitulates phylogeny" provided evolutionists with a working method whereby they could unravel the otherwise unattainable phylogeny of living organisms. Because of its simplicity of statement, the clear symmetry it postulated between the two known developmental processes of ontogeny and evolution, and the considerable evidence apparently supporting it, the biogenetic law was widely accepted by biologists and served as the basis for the surge of embryological research that continues unabated to this day. Moreover, the biogenetic law has become so deeply rooted in biological thought that it cannot be weeded out in spite of its having been demonstrated to be wrong by numerous subsequent scholars. Even today both subtle and overt uses of the biogenetic law are frequently encountered in the general biological literature as well as in more specialized evolutionary and systematic studies. And references to it appear in the most unlikely books, such as the well-known Dr. Spock's *Baby and Child Care*. The chapter "Your baby's development" (Cardinal Giant edition, 1957, p. 223) opens with the statement, "He's repeating the whole history of the human race," and includes the following passage:

> Each child as he develops is retracing the whole history of mankind, physically and spiritually, step by step. A baby starts off in the womb as a single tiny cell, just the way the first living thing appeared in the ocean. Weeks later, as he lies in the amniotic fluid of the womb, he has gills like a fish. . . .

Haeckel devoted much of his energy to the popularization of his ideas and would have been delighted with this advocacy of his central evolutionary concept.

While Haeckel's ideas are reaching countless millions of parents, few biologists outside of ichthyology and evolutionary biology have ever heard of Berg. His major study, *Nomogenesis*, probably has had little or no influence on the development of evolutionary thought and is almost unknown today. Berg suffered from the disadvantage of publishing his ideas after Haeckel and just before the first major synthesis, in the late 1920's, of the contributions of genetics to evolutionary theory. Many of the problems raised by Berg were solved by genetics or vanished as real problems in the light of newly gained knowledge of hereditary mechanisms.

Yet both authors focused on the same evolutionary problems, used the same type of factual evidence and lacked or ignored other, similar information, used the same approaches in their analyses, and reached the same general sort of conclusions. Their entire approach and their conclusions are of great importance to any biologist interested in evolutionary theory, not because of their correctness, but quite the contrary, because of their incorrectness. These books provide an excellent example of the myriad of pitfalls awaiting evolutionary biologists. It was my experience while reading both works that these many problems became far clearer than from the reading of many excellent recent treatments of evolutionary theory. Berg's *Nomogenesis* is the better book in this respect for most readers of *Science* because it is the more recent, benefiting from 50 years of biological research that was not available to Haeckel, because it is shorter and better organized, and because it is available in English.

Both Haeckel and Berg considered evolutionary mechanisms from the viewpoint of comparative morphology and embryology and with a broad training in systematics. Both workers had a wide and detailed knowledge of animal and plant groups. Neither had any deep knowledge of or interest in functional morphology (physiology) or the ecological relationships between organisms and their environment beyond the obvious and broadest concepts. And most important, neither had available or took advantage of post-1900 knowledge of hereditary mechanisms. (In fairness to Berg, it must be noted that the full implications of genetics for evolutionary theory were not appreciated until a decade after the publication of the Russian edition of his book.) Consequently, for both Haeckel and Berg the result of evolutionary mechanisms is a pattern of extreme order that could be seen throughout the spectrum of plant and animal groups. No indications of chance or random mechanisms were apparent to them, nor were they aware of any processes that would introduce chance into evolutionary mechanisms; both authors rejected chance-based evolutionary mechanisms emphatically and completely from their theory. (It should be mentioned that some modern evolutionary biologists still have difficulty in accepting chance-based evolutionary mechanisms in spite of the overwhelming evidence supporting them.) Because the biotic world appeared to be extremely ordered, the evolutionary mechanisms producing it had to be ordered mechanisms or a set of scientific laws in the classical sense. Haeckel outlines a set of "Ontogenetische Thesen" (pp. 206–10)—including his most famous one (No. 41), "Die Ontogenesis ist die kurze und schnelle Recapitulation der Phylogenesis. . . ." (p. 210)—and a set of "Phylogenetische Thesen" (pp. 256–59). The very title of Berg's book implies mechanisms in accordance with law, and in his concluding chapter Berg stresses and restresses this orderliness.

With the conviction that evolution proceeds according to a set of fixed laws, and with their extensive knowledge of embryology, it must have been an exceedingly simple step for both Haeckel and Berg to consider ontogenetical development and evolutionary development as two closely related expressions of the same general time-related biological mechanism. Hence clues to evolutionary mechanisms could be obtained from study of ontogenetical mechanisms, many of which follow highly exact and regulated laws.

Unfortunately, evolutionary development and ontogenetical development are separate and distinct time-related biological processes which have an extremely complex relationship to one another that precludes a simple understanding of evolutionary mechanisms and sequences through study of ontogenetical mechanisms. Evolution does not follow a set of ordered laws as expressed by Haeckel and Berg, and chanced-based mechanisms are very important; hence these volumes cannot be recommended as a source of accepted evolutionary ideas. Yet they are books that should be carefully studied against the background of modern evolutionary theory as a means of seeing old, important, and still unsolved evolutionary problems from a viewpoint quite different from the now-orthodox synthetic theory; I recommend both books very strongly on these grounds. The availability of Berg's *Nomogenesis* and pertinent parts of Haeckel's *Generelle Morphologie* as reprint volumes is of great value to all evolutionary biologists. Unfortunately, Haeckel's ideas are still inaccessible to most American biologists; I am unaware of any English edition of his *Generelle Morphologie*. In view of the widespread influence of Haeckel's evolutionary ideas, an English edition of his major work would be most valuable to evolutionary biologists.

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The Fruits of Travel

William Bartram: Botanical and Zoological Drawings, 1756–1788. JOSEPH EWAN, Ed. American Philosophical Society, Philadelphia, 1968. xiv + 180 pp., illus. $35. Memoirs of the American Philosophical Society, vol. 74.

The illustrations in this book are so striking that they tend to obscure the fact that it is not a mere picture book but a scholarly contribution to the history of American natural history.

William Bartram (1739–1823) was the son and traveling companion of our best-known Colonial botanist, John Bartram (1699–1777). William was a failure as a farmer and was also unsuccessful as a businessman, but he developed into an influential writer and a first-class artist. His book *Travels through North and South Carolina, Georgia, East and West Florida, the Cherokee country, the extensive territories of the Moscogulges, or Creek Confederacy, and the country of the Choctaws; containing an account of the soil and natural production of those regions, together with observations on the manners of the Indians* has a title that needs little elaboration. It also tells us what Bartram's chief interests were and where he traveled and collected the specimens that are depicted in the folio