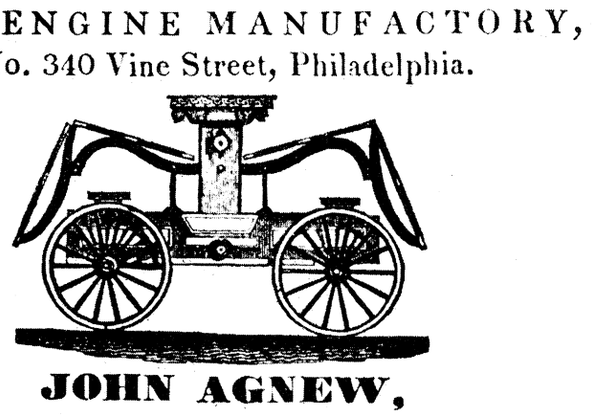

Cover advertisement from the *Journal of the Franklin Institute*, July 1846. "Building fire engines was one of [Philadelphia's] mechanical specialties. . . . The talents required . . . rather naturally led Philadelphia mechanics in two related directions—the production of steam engines and of machine tools." Thomas P. Jones, the editor of the *Journal*, "had also once engaged in the manufacture of fire engines [and] carried advertisements in his *Journal* which called attention to their increasing versatility." [From *Philadelphia's Philosopher Mechanics*]

have made the presentation informative as well as engaging.

Overall, this book is an exceptionally good one. It demonstrates that an institutional study can provide a fresh perspective on a long-standing issue. During the Institute's early years, the relationship between science and technology was under continuous scrutiny by practitioners and by the public. Briefly the philosopher mechanics seemed to link the two. Then the coordination fell apart. Were the assumptions of a relationship false? Was the approach of the Institute inadequate? Sinclair raises and works with such problems, but the problems are larger than the Institute, whose experience remains a provocative anomaly. This study of Institute personnel and practice underscores the point that engineers, educational leaders, scientists, and industrialists had much in common and could work constructively together during the first half of the 19th century. Backgrounds and goals were less diverse than they would be among such groups in later generations.

SALLY GREGORY KOHLSTEDT
History Department,
Simmons College,
Boston, Massachusetts

Meanings of Reductionism

Studies in the Philosophy of Biology. Reduction and Related Problems. Proceedings of a conference, Bellagio, Italy, Sept. 1972. FRANCISCO JOSÉ AYALA and THEODOSIUS DOBZHANSKY, Eds. University of California Press, Berkeley, 1975. xx, 390 pp., illus. $22.50.

There has been a philosophy of science ever since there has been science. Only in the present century, however, and increasingly in recent years, has the philosophy of science been formally recognized as a professional and pedagogical specialty. Early in this movement it was generally assumed that an acceptable philosophy of science was, or would be, derived from the physical sciences. Biologists soon began to object to that exclusive approach, and the question arose whether and in what way a philosophy including the life sciences would differ from or add to one based exclusively on the physical sciences. It is particularly interesting that a number of physical scientists who began to consider living organisms some 30 years ago did so in the expectation or hope of discovering either new physical principles or nonphysical ones. Witness, for example, Schrödinger (*1*) and Delbrück (*2*). On the other hand increasing emphasis in biology on its physical and chemical or specifically molecular aspects led many biologists to look toward strictly physicochemical explanations of biological phenomena. Thus in more recent years we have had an eminent molecular biologist, Crick (*3*), adopting an uncompromising physicochemical approach to the properties (but not necessarily the history) of organisms, while an also eminent physical chemist, Polanyi (*4*), maintained that organismal phenomena are not reducible in that way.

In pursuit of such problems in the last ten years or so there have been a number of conferences bringing together physical scientists, life scientists, and philosophers of science. At some of them the meeting of minds has been almost minimal because the vocabularies, premises, and prejudices in the three fields are so different. At others, however, there has been progress in overcoming those handicaps.

The basic problem between the physical and the life sciences on which a philosophy to encompass both must focus involves reductionism, in some sense of that word. One of the most extensive of the relevant interdisciplinary efforts was a series of three conferences at the Villa Serbelloni, Bellagio, Italy, in 1966, 1967, and 1968, arranged by C. H. Waddington, who also edited the three resulting volumes (*5*). The subject of reductionism underlay many of the discussions at those conferences and occasionally surfaced, for instance in a remark by Waddington (a footnote in volume 1 of the publications) that "even the most doctrinaire reductionist cannot tell the biologists just what they have to reduce their systems to." Nevertheless, and rather surprisingly, there was no special focus on reductionism and that was not among the designated topics of any of the conferences.

It is thus particularly welcome that a conference specifically directed to the subject of reductionism was held, also at the Villa Serbelloni, in 1972 and that its content has now been published. It was arranged and the resulting book is edited by Francisco Ayala and Theodosius Dobzhansky, geneticists of successive generations, both specialists on *Drosophila* and both with exceptionally broad biological and philosophical interests. The participants and authors include a wide spectrum of similarly philosophically minded biologists and a few who are more specifically philosophers of science, but no physical scientists strictly speaking. The latter omission, obviously deliberate, is justified by having kept the discussion largely in terms mutually comprehensible. There are still differences in points of view, in interests, and in vocabulary, as is inevitable in a group with such diverse specialties and

backgrounds. There are disagreements, and minor parts of the discussions seem beside the point. Nevertheless a consensus emerges and the subject is greatly clarified, its consideration brought well into a modern context. The philosophical and the operational status of reductionism is made clear, including improved understanding of aspects still controversial.

A principal problem has been to define what is meant by reductionism. The essays in this book illustrate the fact that the word means different things to different people and that anyone who uses it should designate his particular usage. The most definitely distinctive usages are well classified by Ayala in his introduction as ontological, methodological, and epistemological.

The ontological question is whether "the laws of physics and chemistry fully apply to all biological processes at the level of atoms and molecules." Ayala contrasts this with vitalism, which he says is now "practically a dead issue in the philosophy of biology." That does not exclude consideration of whether the laws of physics and chemistry fully apply to organisms above or outside the level of atoms and molecules, which relates more nearly to the stand of most vitalists. I have already mentioned that this possibility motivated some physical scientists in their approach to biology. Indeed some of the chapters in this book are, if not overtly, at least marginally vitalistic in the broader, more usual sense. For example, Skolimowski says, among other things, that "we need not be nervous to the point of obsession or paranoia about the restitution of God and theology when we attempt to extend the reach of our present knowledge [of biological agencies and forces]." Birch endorses Hartshorne's view that "there must be ... something more than mere matter in matter, or Darwinism fails to explain life," and further accepts but does not discuss the possibility "that the subjective aspects of the universe themselves constitute some sort of all inclusive mind." Birch also gives as a "highly speculative" conclusion "that living and non-living matter do not differ in any fundamental way," but in that respect he seems to tend rather toward panpsychism than nonvitalism. Rensch's views are frankly panpsychic and seem to me rather to evade than to face questions of reductionism.

In spite of those and other nuances, there is here a definite consensus in favor of Ayala's ontological version of reductionism, confined to identity of physical, chemical, and biological "laws" or properties at the atomic and molecular levels.

Methodological reductionism refers to the question whether biological explanations should be sought mainly or solely at lower hierarchic levels, ultimately those of atoms and molecules, or at higher levels, or at both lower and higher levels. In practice almost all biochemists and molecular biologists follow methods reductionist in this sense, although this does not necessarily commit them to a philosophical concept of reductionism. In this book the final chapter, by Monod, although its few pages also cover other subjects, is close to extreme methodological reductionism even in a philosophical sense. Incidentally, this chapter is followed by an apparently full transcription of a fascinating discussion in which, in addition to Monod, most of the others present took part: Montalenti, Dobzhansky, Medawar, Ayala, Stebbins, Shapere, Skolimowski, Thorpe, Campbell, and Popper.

The clear consensus on methodological reductionism by all authors, sometimes more implicit than explicit, is what seems to most of us the commonsense view: all levels of the biological hierarchy must be studied if biological phenomena are to be explained. Methodological reduction in its extreme form is not philosophically tenable. Edelman illustrates the consensus with the specific example of theories of antibody formation based mainly on reductionist methods but eventually requiring study in quite the opposite direction, involving cells, organisms, and populations and hence compositionist, although Edelman himself would not state the case in just this way.

An outstanding exception to the consensus should be mentioned. Medawar, drawing examples from neither physical nor life sciences but from geometry, argues that as one goes down a properly sequential hierarchy each level represents a special case of the last and that there is progressive enrichment because there is restriction, not expansion, of the range of transformations. For the (nonmathematical) sciences, his hierarchy has physics at the top, sociology at the bottom, and organismic biology in between. Then for him "biology [and also sociology] is not 'just' physics and chemistry, but a very limited ... part of them." This is surely thought-provoking even for those of us who also find it just provoking.

Ayala's third category of reductionism, epistemological, refers to the question "whether the theories and experimental laws formulated in one field of science can be shown to be special cases of theories and laws formulated in some other branch of science." It is reductionism in this sense that most concerns both biologists and philosophers of science, in the form of reduction of the life sciences to the physical sciences. There is quite general agreement that complete reduction in this sense has not in fact occurred. The question worthy of discussion is therefore rather whether this sort of reduction of biology to physics and chemistry is possible in principle and thus is an acceptable position in the philosophy of science. Biologists who in practice follow reductionist methodology would seem likely to be motivated also by an epistemological reductionist philosophy. Some of them do espouse that view, although not always with complete clarity or conviction. Crick elsewhere (*3*) and Monod and Medawar in this book are examples to this point. Nevertheless organismal and evolutionary biologists, almost without exception, and many molecular biologists maintain that while all physical and chemical "laws" or principles are equally true of living matter and processes organisms also have properties and activities that are not special cases of those valid in physics and chemistry, thus accepting ontological and rejecting epistemological reductionism.

It should be emphasized that the description and explanation of some biological phenomena by physicochemical terms and principles, for example pertaining to the structure and behavior of DNA, is not an example of reductionism in the epistemological sense. Even in this book it is sometimes mistaken as such or is used as evidence for the validity of epistemological reductionism. In fact such reductions are examples of ontological reductionism only. In simpler words, they only illustrate and justify the conviction that chemicals in organisms are constituted and do act in chemical ways. Eccles here puts the matter more clearly, although he leaves it still open to some question. He notes that in practice neurobiological research must be (methodologically) reductionist, but believes that "reductionism fails when confronted by the brain-mind problem." That belief is based mainly on evidence that consciousness arises only in the dominant hemisphere of the brain, which refutes a hypothesis of psychoneural identity. There may still be some question whether some other hypothesis might account for the observations and still be consistent with a reductionist philosophy. Perhaps the recent discovery (since Eccles wrote) of complex determination of left-right dominance in mice will change the questions to be asked here (*6*).

Several authors argue that there are known biological phenomena that not only have not been but cannot conceivably be epistemologically reduced to the physical sciences. Donald Campbell's two chapters do this, but in ways that are open to further

questions. He calls himself and most of the others at the conference reductionists, but apparently on the gounds that he and they believe that biological phenomena can be explained by natural causes. That does not involve anything that is usually or can properly be called "reductionism." Moreover Campbell finally reaches conclusions, such as recommendation of "recognition of a Creator that is what It is for Its own purposes, and free to change those purposes," that are difficult to reconcile with his profession of naturalism and antivitalism. Popper hails examples of limited or partial reductions, considers methodological reduction as one essential in the pursuit of science, but rejects what he calls "philosophical reductionism," which is the epistemological reduction of Ayala and of this review. He maintains that even within the sciences of physics and chemistry, still more in biology, there has never been a *complete* (epistemological) reduction and never can be. In that connection he stresses the phenomenon of consciousness and gives considerable discussion of the old but ever fresh body-mind question.

Goodfield has written a historical review of the philosophies of 19th- and 20th-century physiologists. She finds that they have run the whole gamut from extreme reductionism to extreme antireductionism. She concludes that this has had little influence on the problems they attacked or the methods they used but that it did make a difference in their theoretical approaches. The two other primarily historical chapters will be mentioned even more briefly because I find them somewhat outside the main current of the discussion, Montalenti's because (in my opinion) he fails to substantiate his claim that "the source of . . . the scientific attitude towards the world is to be found in Greek philosophy," and Boesiger's because in his attempt to reinstate Lamarck in the foundations of modern biology he surprisingly omits the most essential part of Lamarck's (admittedly mistaken) theory of evolution.

Beckner was one of the first to distinguish himself as specifically a philosopher of biology (*7*), and his chapter in this book merits special comment although it is far too complex to summarize here. Beckner bases his discussion on hierarchies and discusses reduction as a relationship between theories at different levels of a hierarchy. In the course of doing so he carefully redefines concepts and terms and shows the fallacies in some considerations of reduction. He does not take a stand between extreme reductionism and antireductionism, and his treatment makes it clear that such a stand is neither necessary nor advisable. He says, "The important thing is not so much the truth about certain reductionist theses, but insight into the conditions and strategies of the *application* of one science to another."

In addition to their organizing and editorial duties and to Ayala's summarizing, unifying, and clarifying introduction, Ayala and Dobzhansky have each written a chapter in the book, both among the best. Dobzhansky's chapter is a splendid summary of the synthetic theory of evolution which he has done so much to establish and advance. Ayala discusses the concept of biological (evolutionary) progress, with emphasis on a distinction between general and particular (what I call ad hoc) progress. Neither chapter, perhaps rather oddly, is devoted primarily to questions of reductionism, but both involve considerations essential to that subject. That is demonstrated by Ayala's last words: "Evolutionary progress . . . can be interpreted as a gradual departure from the importance of physicochemical laws in determining the relevant aspects of the behaviour of organisms."

After discussion with Medawar, Edelman, and Popper at the conference, Goodfield added a mournful postscript to her manuscript, including the feeling that perhaps "So far as the course of science goes, [the question of reductionism] becomes as irrelevant as whether or not [a scientist] regularly beats his wife on a Saturday night." No reader of this volume will agree, and certainly their contributions to the subject demonstrate that Goodfield herself, Medawar, Edelman, and Popper do not really agree.

GEORGE GAYLORD SIMPSON
University of Arizona and
Simroe Foundation, Tucson

References

1. E. Schrödinger, *What is Life?* (Cambridge Univ. Press, Cambridge, 1944).
2. M. Delbrück, *Trans. Conn. Acad. Arts Sci.* **38**, 173 (1949).
3. F. Crick, *Of Molecules and Men* (Univ. of Washington Press, Seattle, 1966).
4. M. Polanyi, *Science* **160**, 1308 (1968).
5. C. H. Waddington, Ed., *Towards a Theoretical Biology* (Aldine, Chicago; vol. 1, 1968; vol. 2, 1969; vol. 3, 1970).
6. R. L. Collins, *Science* **187**, 181 (1975).
7. M. Beckner, *The Biological Way of Thought* (Columbia Univ. Press, New York, 1959).

Post-Copernican Transformations

The Heritage of Copernicus. Theories "Pleasing to the Mind." The Copernican Volume of the National Academy of Sciences. JERZY NEYMAN, Ed. MIT Press, Cambridge, Mass., 1974. x, 542 pp., illus. $25.

The U.S. National Academy of Sciences has had the splendid idea of preparing a festschrift to commemorate the recent 500th birthday of Nicholas Copernicus. It opens with an account of Copernicus's life and work by Jerzy Neyman. This emphasizes the intensity of Copernicus's desire to understand the motions of the planets in terms of a theory in which the intellectual qualities of simplicity and clarity were more important than the mere capacity to produce verifiable predictions. Moreover, what appeared clear and simple to Copernicus had none of that appeal to the intellectual establishment of his day. Copernicus himself, who put off publication to the last minute, died before the displeasure of the Church could be fully expressed, but his book remained for two centuries on the Index of books forbidden to Catholic readers, and it was not until the time of Kepler, almost two full generations after Copernicus's death, that astronomical observation revealed facts that were easier to interpret on his theories than by reference to the classical system of Ptolemy. Copernicus does indeed set an extraordinarily high standard of devotion to intellectual clarity, in the face of disapproval of powerful public figures and at best lack of positive support from the known facts.

The remainder of the book consists of 24 essays which explore 20th-century advances in science to see whether any of them match up to Copernicus's work, either in intellectual boldness or in transforming the picture man has of his place in the universe. This is a most happily chosen formula, since it justifies concentration on all the most exciting and novel developments in recent science. There are four essays on astronomy and cosmology, six on biology, four on chemistry and physics, three on mathematics in general with another three on statistical modes of thought, and finally four on various aspects of technology. All the writers are leaders in their fields, and they have written here in a manner that transcends any narrow specialization. Most of them give a good deal of the background history, which serves to emphasize the character and scale of the recent advances they are describing. They have also taken great trouble to make comprehensible some of the very difficult and noncommonsensical ideas which are the real triumphs of science's penetration into the unknown. There is a remark in the introduction to the section on chemistry and physics that in fact can be applied to the book as a whole: