approaches were used to reach the same result. I believe that this is a unique book in that the Soviet authors openly explain how, after Lysenko forbade all genetics research in the Soviet Union in 1948, Soviet specialists drastically changed their methods of the study of monogermity. Instead of pure genetic work, they undertook a gigantic project to search for plants with flowers of predominantly male or female type. This search was organized to exclude genetic methods. Next, various lines with separately flowering plants were cross-pollinated and individual forms giving monogerm progeny were selected. The descriptions of these massive numbers of crossings and their results are of great interest for Western scientists. It is ironic to read that, paradoxically, despite the Soviet scientists' desire to turn away from genetics, their work resulted in a typical genetics investigation.

The central part of the book is devoted to Savitsky's hypothesis of the role of the *M–m* locus in the determination of the mono- and multigerm character of sugar beet. The most interesting part here is the detailed explanation of the screening procedures used by Soviet specialists during the search of the new representatives of *M–m* alleles which enabled them to select and study in detail four new alleles of this locus in different varieties of sugar beet.

Western plant geneticists will be interested in this book because it represents a unique collection of Soviet data over a long period of time. Because the authors did not limit themselves to a discussion of their own work, but have tried to compare their data with the results of Western researchers, it is particularly informative. It would be of even more interest if the book were to be translated into English. □

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An arrow's point

Robert M. Wald

The Physical Basis of the Direction of Time. By H. D. Zeh. *Springer-Verlag: 1989. Pp.166. £6.50, DM18.*

THE nature of time irreversibility in the laws of physics and in physical phenomena remains one of the most intriguing fundamental issues in physics. The presently known dynamical laws of physics are exactly CPT invariant, and the time-reversal asymmetry inferred from observed CP violation is extremely small. Nevertheless, most macroscopic physical phenomena we observe in our daily lives display a gross time asymmetry. Most prominent among these observed "arrows of time" is the "thermodynamics arrow" represented by the law of increase of entropy. In addition, there is the obvious fact that our perceptions of the past and future are totally different — we cannot 'remember' the future. Indeed, it takes considerable training in physics to learn to treat the 'past' and 'future' on a comparable footing.

The (nearly exact) time symmetry of the laws of physics is not necessarily in any conflict with the "arrows of time" observed in physical phenomena: time-symmetrical dynamical equations admit time-asymmetrical solutions. In particular, the thermodynamic arrow of time can be attributed to 'special' initial conditions for our Universe. Nevertheless, most physicists expect (or at least hope) that a more fundamental origin of the observed arrows of time eventually will be uncovered, and that some deeper relationships between them will be found.

It seems clear that some arrows of time — such as the retardation of radiation — are closely related to the thermodynamic arrow. It is less clear that there is a relationship between the thermodynamic arrow and the arrow of time in quantum measurement theory associated with reduction of the state vector. (Indeed, it is debatable whether there really is an arrow of time in quantum measurement theory, although Penrose has recently provided a strong argument for the presence of such an arrow.) It is far less clear that the arrow of time associated with the expansion of the Universe bears any relationship to the other arrows. The ideas and speculations of about 10 years ago on the nature of the various arrows of time and the relationships between them were discussed and summarized by Paul Davies in his book *The Physics of Time Asymmetry*. Since then, there have been several noteworthy developments, mainly arising from research in general relativity and quantum gravity. In particular, Penrose has proposed that the vanishing of the Weyl tensor at initial singularities could account for the thermodynamic arrow. In quantum cosmology, proposals have been advanced for boundary conditions which determine the wavefunction of the Universe; the relationship between the expansion of the Universe and the other arrows of time can then be addressed, at least in the context of the highly simplified and idealized models for which the proposals can be given concrete form.

Zeh provides a concise, technically sophisticated and up-to-date discussion of research on the arrows of time in physics. He displays a wide familiarity with the relevant modern literature in the rather diverse fields of study related to the arrows of time. Indeed, one of the most valuable aspects of his book is the bibliography of the original research papers. However, much of the book reads as a terse commentary on these papers. The author frequently attempts to summarize sophisticated and controversial ideas in a sentence or two, with the result that the reader will have little chance of following the discussion unless he already is thoroughly familiar with these ideas. In addition, although I did not encounter any serious technical errors, there are several slight misstatements and other minor flaws, particularly in the last two chapters on space-time structure and quantum cosmology. (An example of such a flaw is the failure to draw a distinction between Penrose's (time symmetrical) strong cosmic censor hypothesis — which postulates that space-times must be globally hyperbolic, thereby allowing one to distinguish between 'past' and 'future' singularities — and Penrose's (time asymmetrical) Weyl tensor hypothesis — which postulates that the Weyl tensor must vanish near past singularities.) These flaws contribute to the difficulty in following some of the arguments.

Zeh's main thesis seems to be that the expansion of the Universe provides a "master arrow of time" from which all others follow. (However, this conclusion is stated more clearly and explicitly on the jacket than anywhere in the book.) The basic idea behind this suggestion has to do with the fact that in minisuperspace models, the radius of the Universe formally plays the role of 'time' in the Wheeler–DeWitt equation satisfied by the wavefunction of the Universe. If one imposes boundary conditions that select real solutions of the Wheeler–DeWitt equation, then — at least in some formal sense — there should be a symmetry between expanding and contracting phases in the evolution of the Universe and, hence, all other arrows of time should correlate with the expansion of the Universe.

A similar conclusion was drawn by Hawking several years ago, although he retracted this conclusion after it was recognized that most classical trajectories associated with the wavefunction of the Universe probably would not display a symmetry between the expanding and contracting phases. My own view is that there are sufficiently many unresolved interpretive issues concerning the wavefunction of the Universe that it would be premature to draw any physical conclusions at the present time. Despite these criticisms, however, Zeh's book provides a very useful guide to modern research on the nature of the arrows of time in physics. □

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