ought to do as philosophers or historians of science when faced with difficulties in the interpretation of some figure's work. Clearly, hero-worship and assumptions of hyper-rationality can cloud our judgment, and this book offers an antidote to those tendencies by showing how varied the creative sources for and targets of a scientific argument can be. It also leaves us with some unanswered questions about the antidote's possible side-effects. These questions are well worth studying.

SCOTT TANONA, INDIANA UNIVERSITY

David Z. Albert, ***Time and Chance***. Harvard University Press (2000), xi + 172 pp., $29.95 (cloth).

For well over a century, physicists and philosophers have wrestled with the conundrum of how to reconcile the obvious temporal asymmetry of everyday physical phenomena (spilled glasses of water, cracked eggs, dissipating gases, etc.) with the temporal symmetry of fundamental physical laws. David Albert takes on this puzzle in his second book, *Time and Chance.*

Two key components of discussions of the second law of thermodynamics (entropy never decreases with increasing time) are (1) time-symmetric physical laws and (2) some kind of statistical postulate, which essentially consists of assigning a probability distribution to the set of microstates corresponding to each possible macrostate of the system in question. (A third component of many approaches is the derivation of time-asymmetric "master equations"; for a critique of this "dynamic asymmetry" approach, see Price 1996, 37–48.) The greater part of the book focuses on exploring the nature of the paradox and proposing a solution in the form of a novel formulation of the statistical postulate.

Albert begins by explaining what he means by time-symmetric laws. His definition is more restricted than the standard one, which allows for time-reversed states in the construction of a time-reversed sequence of events. For instance, the usual example of a time-reversed history in the context of classical electromagnetic theory would allow for the spatial reversal of fields—otherwise the history would not be reversible (think of a film clip of a charged particle moving in a constant magnetic field; playing back the clip in reverse violates the theory, because the magnetic field would exert a force in the opposite direction if the particle's velocity were reversed). Albert argues that reversing the orientation of electric or magnetic fields has nothing to do with time reversal and should not be allowed. Therefore electromagnetism only fulfills what he calls "partial time symmetry" (which is nevertheless still in conflict with the asymmetry of the

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second law). This claim is controversial; for a detailed objection, see Arntzenius (2001).

Discussions of entropy increase and "irreversibility" are often riddled with references to the observer's inability to know for sure which of a large number of microstates a system is actually in, as if that has something to do with the system's actual behavior. (I recall a Java applet purporting to demonstrate that a gas never returns reversibly to its original configuration, even under an exact velocity reversal, because of "roundoff error"—as if Nature has to worry about roundoff error!) Albert commendably dismisses this fallacious reasoning in Chapter 3.

Albert then rehearses the well-known reversibility objections to Boltzmann's proposed "counting of microstates" solution. These consist in pointing out that application of the statistical postulate in the form of assuming equal a priori probabilities for all microstates corresponding to a given macrostate at any arbitrary time τ, together with time-reversible laws, gives rise to a situation in which entropy is just as likely to increase toward the past as toward the future, in contradiction to our everyday experience. Thus, while such an assumption beautifully predicts just what we want to see in the future direction (i.e., entropy tending to increase for times greater than τ), it unfortunately also retrodicts exactly the same phenomenon toward the past (which means that states prior to τ progressed toward lower entropy values in the increasing t direction). Albert presents this difficulty in a clear and illuminating way.

Much of the book is spent in arguing that, given time-symmetric physical laws, there is no way out of the time symmetry resulting from the usual formulations of the statistical postulate (SP), and that what is needed is a modification of the SP incorporating what Albert calls a "Past-Hypothesis." This "Past-Hypothesis" is essentially the assumption that information we think we have about the past (such the low-entropy origin of the universe) is correct—despite the fact that, merely on the basis of counting of microstates, it's far more likely that our memories and records randomly arranged themselves into states that merely appear to indicate a lower-entropy past. (Albert uses as an example a photograph of himself: it's far more likely that the photograph materialized as random fluctuations of molecules than that someone actually took a photo of David Albert. The Past-Hypothesis, in this case, is that the latter did occur.) Conditionalizing on this background knowledge (which we have only of past events but not future ones[1]), prevents the troublesome increase of entropy toward the past resulting from the usual SP formulation.

1. Albert notes that nothing rules out, in principle, a "future hypothesis," but observes that, thus far, our experience is "confirmatory of a past hypothesis but not of any future one" (118–119).

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As Albert points out, such background knowledge is based not on directly observable empirical features of the world, but on records. In Chapter 6, Albert probes the notion of "record" in some depth. He establishes that recording of facts requires a ready state of some device, which can only be established by the prior ready state of some earlier device; this apparently results in an infinite regress of ready states. He points out that the Past-Hypothesis can halt the infinite regress by serving as "the mother of all ready conditions." The Past-Hypothesis thus serves a dual role as the appropriate modification of the statistical postulate and as the required initial ready state.

Albert's modified SP does in fact work as advertised—it successfully predicts the general increase in entropy that we observe only in the future direction. For some, however, this may not be a fully satisfying solution. For example, Dieter Zeh (cf. 1989, 33) expects a theory of thermodynamics to explain both (1) the dynamics of entropy increase[2] and (2) the "improbable initial conditions" which Albert simply assumes (as his Past-Hypothesis). As noted above, the assumption is motivated and justified by its dual role as the basis of the reliability of records as well as the basis of the entropy gradient toward the future. But the difference in approach of Albert and Zeh to the problem of entropy increase points to a deeper problem of exactly what a statistical theory of thermodynamics ought to be trying to explain.

Huw Price addresses just this question in his (1996). Should we try to explain what "drives" entropy to increase toward the future, or it is sufficient to show that, in the absence of low-entropy constraints, matter naturally favors high-entropy states? Price argues for the latter, and Albert essentially follows this route by showing that, once one conditionalizes on the low-entropy past, the second law follows simply from the counting of microstates pioneered by Boltzmann. The explanation of the highly improbable low-entropy past then becomes relegated to cosmology (which, as Zeh notes, faces its own difficulties in the form of the so-called "horizon problem" (Zeh 1989, 126)).

Much of Albert's discussion in Chapter 6 takes off from Lewis' well-known work on the asymmetry of counterfactual dependence (e.g., Lewis 1979) and it would have been good to include reference to such works. Albert departs from Lewis' formulation in that he attributes temporal asymmetry not to the large number of future traces of a present event, but to the quality of single records of such an event.[3]

2. Zeh takes such a dynamics as comprising such things as asymmetrical "master equations," mentioned above as the third, "dynamic asymmetry" component of some statistical theories of entropy increase.

3. Horwich (1988, 82) makes a similar observation about quality vs. quantity of traces.

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The final chapter of the book proposes using the GRW collapse theory (cf. Ghirardi, Rimini and Weber, 1986) as an alternative to the Boltzmannian solution. The GRW theory is a proposal to solve the measurement problem of quantum mechanics by postulating an actual physical collapse of the wave function. Such a collapse is fully indeterministic and time-asymmetric. Using the GRW theory as a basis for entropy increase thus falls into the "dynamic asymmetry" approach.

(This reviewer personally has no appetite for explicit collapse theories. While this is not the place for anything resembling a substantive critique—Albert himself gives a good one in his first book, *Quantum Mechanics and Experience,* (1992, 92–111)—such theories seem too obviously ad hoc, too reminiscent of Ptolemaic epicycles. They posit a phenomenon that is essentially never detectable—and which must be delicately tailored "by hand" to get around numerous difficulties—in order to solve a conceptual problem of quantum theory (the measurement problem). As Einstein once said (perhaps unfairly) of David Bohm's hidden variable interpretation of quantum theory, that kind of solution seems "too cheap to me.")

On the nitpicking editorial side, the book seems to be missing a reference for the GRW theory, on which nearly an entire chapter is focused. In addition, I found the index rather inadequate. Important and frequently used terms such as "Past-Hypothesis," "statistics," "statistical postulate," "Newton/Newtonian," "reversible/reversibility," "thermodynamics," and "time," do not appear in the index, which is only two pages long.

Finally, a note about style. Albert's style is famously relaxed and conversational, almost stream-of-consciousness. One might think this would be conducive to easy reading, but in some cases it is not. The numerous interjections of parenthetical remarks could be thinned down to only those that are essential for clarity; some merely serve to interrupt the flow of thought. Albert's tendency to repetitious, run-on sentences (including the use of commas where semicolons are needed) can also make understanding more difficult. Here is one example, on page 62, which cries out for judicious editing:

> "It sounds very much as if it is doing nothing more than reminding you that what you are saying when you say something like that is that X is the case at the time in question, and moreover, that you have no more reason for believing that the system is in any particular one of the microconditions compatible with X at the time in question than you have for believing that it is in any other particular one of the microconditions compatible with C at the time in question, that (insofar as you know, at the time in question) nothing favors any particular one of those microconditions over any particular other one of them, that (in other words) the probability of any particular one of

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those microconditions obtaining at the time in question, given the information you have, is equal to the probability of any particular other one of them obtaining at the time in question."

Surely there must be a clearer way to convey the meaning of this sentence.

Such flaws notwithstanding, the book is a sustained and penetrating look into the heart of a paradox, with proposals for solution which will no doubt generate further discussion and progress.

R. E. KASTNER, UNIVERSITY OF MARYLAND COLLEGE PARK

REFERENCES

Albert, David (1992), *Quantum Mechanics and Experience.* Cambridge: Harvard University Press.
Arntzenius, Frank (2001), "Time Reversal Operations, Representations of the Lorentz Group, and the Direction of Time", preprint.
Ghirardi, G. C., A. Rimini, and T. Weber (1986), "Unified Dynamics for Microscopic and Macroscopic System", *Physical Review* D 34: 470–491.
Horwich, Paul (1988), *Asymmetries in Time.* Cambridge: MIT Press.
Lewis, David (1979), "Counterfactual Dependence and Time's Arrow", *Nous* 13: 455–476.
Price, Huw (1996), *Time's Arrow and Archimedes' Point.* Oxford: Oxford University Press.
Zeh, Dieter (1989), *The Physical Basis of the Direction of Time.* Heidelberg: Springer-Verlag.

Mayberry, J. P., ***The Foundations of Mathematics in the Theory of Sets. Encyclopedia of Mathematics and Its Applications Ser., Vol. 82***. Cambridge: Cambridge University Press (2000), xx + 429 pp., index, cloth $80.00 (cloth).

Mayberry gives a powerfully informed, tough-minded argument that mathematics absolutely needs a foundation and has one established in practice: the axiomatic method as interpreted in Cantorian set theory. The last third of the book suggests we might eventually abandon Cantor in favor of what Mayberry calls Euclidean set theory. Euclidean set theory also yields a novel approach to non-standard models of arithmetic, related to work by Edward Nelson and Jan Mycielski (391).

Mayberry begins with the notion of a number, which he takes in the sense of Aristotle's *arithmos,* a collection of specific things. This sense survives in English today. Mayberry gives as example "Lieutenant Lightoller was among the number of survivors of the Titanic" (99). He cites Aristotle often, to good effect, and with real sensitivity to the texts, especially on the variety of ways in which things are said "to be," and on the nature of proof. And he discusses Newton's deliberate gesture changing the meaning of number, against Barrow's resistance (191–192).

Then comes the question of finitude, in the ancient meaning of "finite" as "definite, determinate, bounded." Which *arithmoi* are "finite"? Which

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