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Book Review: *Time's Arrow and Archimedes' Point*[1]

Time's Arrow and Archimedes' Point. Huw Price, Oxford University Press, Oxford, 1966.

Huw Price, a Reader in Philosophy at the University of Sidney, Australia, has written a book addressed to physicists, philosophers, and general readers about the perception and treatment of time in the formulation of fundamental physical theory. In particular he is concerned with questions like: "Could—and does—the future affect the past? ... What would such a world be like? Is our world like that?" He claims, quite correctly, that "philosophers as well as physicists often fail to pay adequate attention to the [asymmetric] temporal character of the viewpoint which we humans have on the world." To overcome this human bias and achieve "temporal correctness" Price advocates the "Archimedean view of reality ... the view from *nowhen*" (recalling Archimedes' boast that he could lift the whole earth, given a fixed point outside of it and a long enough lever).

Price then argues, to quote the book jacket, that "in missing the Archimedean viewpoint, modern physics has missed a radical and attractive solution to many of the apparent paradoxes of quantum physics... these paradoxes can be avoided by allowing that at the quantum level the future does, indeed, affect the past. This demystifies nonlocality... ." Hardly a modest claim, even for a book by a philosopher, and this immodesty is unfortunately not confined to the jacket.

To reassure the skeptical reader, the book comes with many jacket blurb endorsements by physicists and philosophers. The most restrained of these is by Roger Penrose, who says, "Huw Price provides a thoughtful (and thought-provoking) analysis of the time-asymmetry problem of physics which is in many ways deeper and more illuminating than *accounts to be found elsewhere*" (italics mine). I agree with this evaluation. Price conveys a far better understanding of the issues than is found in most other

[1] An abbreviated version of this review appeared in the January 1997 issue of *Physics Today*.

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books devoted to this topic. [I should add, however, that there are many places where, I think, the book misses its mark and also that the book's unnecessary (and unjustified) arrogance will almost surely infuriate most readers, greatly lessening its value to scientists.]

The first main theme of the book is that "The asymmetries of thermodynamics and radiation appear to depend on the fact that the universe had a particular character early in its history: its matter was very evenly distributed, which is a very ordered [low entropy] condition for a system in which gravity is the dominant force." Price then argues that while this initial condition explains the observed "macroscopic" asymmetry, which includes our own biological and psychological make up—the past feels very different to us from the future—it does not imply an *additional microscopic asymmetry* which physicists often mistakenly assume. This he calls μInnocence: "interacting [microscopic] systems are uncorrelated before they interact." This leads to "a deep and almost unrecognized conflict in contemporary physics. If we are to retain T-symmetry, we should abandon μInnocence." Furthermore, "quantum mechanics seems to offer empirical confirmation that μInnocence fails. The failure of μInnocence seems to open the way for a kind of backward causation."

A detailed discussion of the quantum world view is in the last part of the book. After describing the usual paradoxes, Price comes down strongly in favor of what he calls "the common future hypothesis," which is a denial of μInnocence, or independence, to objects which have an interaction in the future. "Compared to all other major approaches, its advantage seems to be that it does not conflict with special relativity," that is, it does not require the "crude" nonlocality that follows from Bell's theorem when backward causation is excluded, because "the point at which [systems] become coupled ... lies well within the light cone of their later [interactions]." In fact, Price advocates a *local* hidden variable theory made compatible with quantum mechanics and special relativity through *backward causation.*

On the whole Price does well in pointing out "a variety of common mistakes and misconceptions about time" and in "sorting out how much of the temporal asymmetry we think we see in the world is objective, and how much is simply a by-product of our own asymmetry." The idea that this and other macroscopic asymmetries in our world are explained by the low-entropy initial state of our universe is of course not original to Price. It goes back at least to Ludwig Boltzmann, as quoted by E. Broda in *Ludwig Boltzmann, Man–Physicist–Philosopher* (Ox Bow Press, 1983, p. 79): "That in nature the transition from a probable to an improbable state does not take place as often as the converse, can be explained by assuming a very improbable initial state of the entire universe surrounding us. This is a reasonable assumption to make, since it enables us to explain the facts of experience...." It is presented succinctly and elegantly by Richard Feynman in *The Character of Physical Law* (MIT Press, Cambridge, Massachusetts, 1967), "it is necessary to add to the physical laws the hypothesis that in the past the universe was more ordered, in the technical sense, than it is today ... to make an understanding of the irreversibility." Price does not quote Feynman, but follows closely the recent very clear formulation of this idea in terms of the "big bang" model by R. Penrose in *The Emperor's New Mind* (Oxfod University Press, Oxfod, 1989, Chapter 5), who takes for the "initial state" of the universe the macroscopically smooth energy density state prevalent soon after the big bang.

Gravity, being attractive and long range, is unlike any of the other natural forces. When there is enough matter/energy around, it completely overcomes the tendency toward uniformization observed in ordinary objects. Hence, in a universe dominated by gravity, like ours, a uniform density corresponds to a state of very low entropy or phase space volume for a given total energy.

The present clumpy macrostate of the universe, consisting of planets, stars, galaxies, black holes, etc., has higher entropy. It can therefore be considered as the "natural" evolution of the initial macrostate toward one with higher entropy. The small amount of local "order" or low entropy we see around us (and elsewhere)—from crystals to complex molecules to trees to brains—is perfectly consistent (and presumably even a consequence) of the much larger increase in the total entropy of the universe above its initial state. The "natural" or "equilibrium state" of the universe is one with all matter and energy collapsed into one big black hole, which, according to Penrose, would have a phase space volume some $10^{10^{120}}$ times that of the initial state.

To be able to make the above type of deductions from the smooth initial *macrostate* of the universe, one has to add something about the initial microstate. It is usually assumed, implicitly or explicitly, that the initial *microstate* was *typical* with respect to some (at least vaguely defined) weight or measure on the different microstates compatible with the initial macrostate, e.g., "uniform" weight to all such microstates. But, accepting this reasonable minimalist assumption of typicality of the initial microstate, one should then be able to decide, at least in principle, what correlations are to be expected in particular situations; no additional independent assumptions about μInnocence would then be necessary or possible. Of course this might still require adopting, as a practical *working hypotheses*, certain rules of thumb about correlations and causations, not only in our daily lives, but also in our scientific work. This, and not some unacknowledged "mistake," seems to me the justification for assuming as a working hypothesis of the lack or irrelevance of certain correlations to which Price so strongly objects.

As a very simple analogy, consider a gas in equilibrium in some confined spatial region, say half a box; it will have uncorrelated velocities despite the many interactions between the particles. If the volume of the confinement region is expanded by the removal of a partition, at $t = t_0$, the system will then find itself in an uncorrelated nonequilibrium initial state with respect to its Hamiltonian for $t = t_0$. Whether enough of this lack of correlation will persist for $t > t_0$ to make the Boltzmann equation valid at later times is a difficult mathematical problem, whose answer Boltzmann assumed to be in the affirmative; for some rigorous results in this direction see Oscar Lanford, (*Physica A* **106**:70, 1981). To make the questions about correlations in this simple system a bit closer to those we might ask about our universe, imagine that at time t_0 many holes are made in the box. The gas expands then into pipes, some of which meet again at a later time t_1. It is clearly a difficult problem to decide what correlations will be present at t_1, but if $t_1 \gg t_0$ and the routes taken by the different streams are sufficiently complex, a good first guess is that there are no significant correlations.

In the above *Gedanken* experiment as well as in the real world, our statements refer to microscopic configurations of the system which are *typical* at $t = t_0$ of the phase space volume associated with a macroscopic system in equilibrium. For such typical configurations we can take the velocities of the atoms in the initial equilibrium gas to be uncorrelated for all practical purposes. See Joel L. Lebowitz (*Phys. Today* **46**:32, 1993) for a discussion in terms of classical physics and Detlef Dürr, Sheldon Goldstein, and Nino Zhangi (*J. Stat. Phys.* **67**:843, 1992) for a quantum mechanical, à la de Broglie–Bohn, version.

I also found that Price is too insistent on the need for time correctness in cosmology, i.e., on the need to treat the final state of the universe in the same manner as the initial state. Price calls the lack of a comprehensive theory of initial and final states cosmology's **basic dilemma**. Now, while it would certainly be nice to have a theory that is able to *explain* the highly improbable smooth initial state of the universe, I am not so worried about the lack of such a theory. I am even less worried about the nature of the universe's final state. As long as we can explain the behavior of our actual and only universe on the basis of some plausible (although highly improbable according to phase-space-volume considerations) initial macro conditions, it seems to me quite reasonable to accept, at this time, Boltzmann's point of view that "one should not expect to deduce it [the initial state] from anything more fundamental." As for a final state, I would prefer to leave this alone for a while unless one could find any evidence that at the present time we can already feel its influence.[2]

The most novel part of the book to me is Price's discussion of causation (I have not read David Hume since college, if then). Causation, which is deeply rooted in our psychology as unidirectional in time (we can with our "free will" affect the future, but not the past), is a very touchy subject in any model of the universe in which time evolution—be it of the classical variables or of the wave function—is described by deterministic or specified probabilistic equations. In Chapters 6 and 7 Price argues for the view that "the asymmetry of causation is a projection of our own temporal asymmetry as agents in the world." He believes, however, that this does not rule out "backward dependence, in circumstances in which an agent's access to past events is limited in certain ways." Consequently, the usual paradoxes associated with backward cuasation in science fiction time travel stories, like killing your mother before she gave birth to you, do not apply to the microscopic world of quantum mechanics, in which we cannot gain complete knowledge of a system's state without affecting that state by our interactions with it (measurement).

Price then goes on to present a good account of the conceptual problems present in our current view of the world, a world where results of measurements, as given by instrument readings, are wonderfully accurately predicted by quantum mechanics, but where the *true* nature of the reality discribed by the theory is very problematic. His discussion of the Einstein–Bohr "debate" about the *completeness* of the quantum description of reality is better than that found in much of the physics literature. He hits the nail on the head when he writes "The EPR [Einstein, Podolsky, Rosen] arguments failed by and large to sway supporters of the Copenhagen Interpretation, but this is perhaps due more to the obscurity of the Copenhagen response than to any compelling counterargument it brought to light." This debate is still very much with us, with many physicists apparently ready to deny the existence of any reality on the microscopic

[2] As remarked by Dennis Sciama (*The Unity of the Universe*, Doubleday, New York, 1961, p. 70), "the uniqueness of the universe ... raises problems, and for the following reason. Scientists normally have available for study many instances of any particular phenomenon. By comparing these instances with one another they are able to distinguish between the fundamental and the accidental aspects of the phenomenon. For example, by comparing many instances of motion under gravitation, Newton discovered that the shape of an orbit is fundamental but its size is not. Now with only one universe available for study, we have no basis for distinguishing between its fundamental and its accidental features. Two choices are then open to us. We can regard all its features as either equally fundamental or equally accidental. For my part, I believe that the aim of science should be to show that no feature of the universe is accidental." To me this seems quite unreasonable as a program: if such a result comes out from the study of the relationships in our actual universe, that is a great bonus, but it may just not be in the cards.

level. This appears to me, however, quite untenable. As R. Penrose puts it in *Shadows of the Mind* (Oxford University Press, Oxford, 1994), "it makes no sense to use the term "reality" just for objects that we can perceive, such as (certain types of) measuring devices, denying that the term can apply at some deeper underlying level. Undoubtedly the world is strange and unfamiliar at the quantum level, but it is not "unreal." How, indeed, can real objects be constructed from unreal constituents?"

Where Price is least convincing is in his argument about the merits of backward causation as a viable explanation of our world. It is not that what Price suggests is clearly wrong, and it certainly should not be dismissed out of hand. What Price does not seem to fully appreciate is the difference between having a general idea, which one can discuss at lunch, and actually providing a consistent physical theory, or even the outlines of one, which implements, in the form of equations, this backward causation. Lacking such a theory, he should have put foward his ideas much more tentatively. It would also have been useful to give some discussion of the work of Yakir Aharonov and L. Vaidman (*Phys. Rev. A* **41**:1, 1990), whose ideas about associating two wave functions to a system—corresponding to past and to future measurements—might in some ways be considered as a *start* toward a well-developed theory incorporating backward causation.

Whether a theory of this kind could really be made viable is another matter. As John Stuart Bell puts it (*Epistemol. Lett.*, February 1977), "A theory may appear in which such conspiracies inevitably occur, and these conspiracies may then seem more digestible than the non-localities of other theories. When that theory is announced I will not refuse to listen, either on methodological or other grounds. But I will not myself try to make such a theory." While Bell's statement does not refer explicitly to the "common future hypothesis," I believe, contrary to what Price feels, that Bell meant it to be included in his statement.

Still, as Robert Browning said, "a man's reach should exceed his grasp, or what's a heaven for?" So, despite many shortcoming and much arrogance, the book is worthy of attention. In fact it is very important to pay careful *attention* to nuances when reading the book or thinking about these matters. Price is well aware of this and nicely illustrates it by a quote from "Marx" at the very beginning of the book, "Time flies like an arrow: fruit flies like a banana."

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