By Craig Callender

TIME'S ARROW should take its place alongside Reichenbach's *The Direction of Time* as one of the finest books in the philosophy of time. It is timely and provocative, and it will be required reading for anyone thinking about time's arrow. Although its virtues are numerous, perhaps the most significant is its identification of the all-too-pervasive 'temporal double standard': the fallacy of explaining a temporal asymmetry by illicitly appealing to another hidden difference between the past and future. With great clarity and liveliness Price exposes this reasoning for what it is, a fallacy, and he leaves philosophers and physicists with no excuse to ever make it again.

Part of what makes a provocative book provocative is that it includes some surprising claims. That *Time's Arrow* contains many makes it both a significant contribution to the literature and also entertaining. When Price is provocative, for instance about the view from 'no-when' or the real nature of the temporal asymmetry of radiation, on balance I end up agreeing with him. However, there are some arguments with which I disagree, and in a forum like this it seems appropriate to dwell on these, however much I sympathise with the majority of the work. Price seeks to understand physics from what he calls the 'atemporal' perspective. In his desire to carry out this worthwhile project he is sometimes, in my opinion, a bit overzealous when fighting the cause of temporal symmetry. What follows are descriptions of three spots where I believe zeal got the better of him.

What Is the Problem of Time's Arrow?

My first worry is about the way Price understands the very problem. The puzzle of time's arrow is that of explaining why we have temporally asymmetric phenomena, such as thermodynamic processes, in a world allegedly governed by time reversal invariant (TRI) laws. To reconcile these phenomena with TRI laws we must assume the universe has temporally asymmetric boundary conditions. Price takes the problem to be that of *explaining these asymmetric conditions*. Doing so presents us with the following basic dilemma: (in a closed universe) either "entropy must decrease toward a big crunch, as well as a big bang, or ... the low entropy big bang is simply not explicable by a time symmetric physics" (p. 94). The first alternative, that of a so-called Gold universe, is one wherein thermodynamics holds for the expansion period of the universe but anti-thermodynamics (entropy decrease) obtains in the recontraction period. There is no net asymmetry in such a universe. Speaking loosely, then, Price's basic dilemma asserts that the only way to explain the temporal asymmetries is to say that there aren't any.

This resolution of the problem leads one to suspect that Price has a problem in mind distinct from the traditional one. The traditional problem left to us from Boltzmann's debate with Loshmidt, as I understand it, is that since the fundamental dynamics are time symmetric, statistical mechanics makes the same predictions toward the past as toward the future. Not only is it overwhelmingly probable that present states evolve toward equilibrium, it is also overwhelmingly probable that present states *evolved from* equilibrium states. The latter simply doesn't happen, however. Roughly put, the traditional problem of time's arrow therefore amounts to explaining this faulty retrodiction away.

The traditional problem should be distinguished from Price's. Price wants to explain why entropy was ever low in the first place. This might be taken for the traditional one, for it too originates from the fact that entropy was lower earlier. But the difference is easy to see after reflecting on Price's claim that the project of seeking a dynamical explanation for entropy increase simply *misses the point* (p. 40). A dynamical explanation of entropy increase (which would require a non-TRI dynamics, as in the recent GRW—Ghiradi, Rimini, Weber—dynamics for quantum mechanics) does not miss the point if the problem is the traditional one above. Given the right sort of non-TRI dynamics we would know why entropy was earlier lower, in the sense that we would know entropy always increases. That is, we would know why entropy doesn't increase toward the past as well as toward the future, which would answer what I'm calling the traditional problem. Yet we still wouldn't be able to answer Price's worry about why it was ever in non-equilibrium in the first place. We would only know that *if* the universe were out of equilibrium, entropy would increase and not decrease; we wouldn't know why the universe began (or nearly began) out of equilibrium. My question is: is this further worry Price wants addressed worth answering?

I don't know that it is. Explaining why earlier states of the universe had low entropy presumably means providing a reason to think these low entropy conditions inevitable or at least improbable. But how can we possibly do this, especially if these low entropy conditions are boundary conditions of the universe? Some cosmologists, for example, Hawking, believe they can explain the universe's boundary conditions, and Price quite rightly takes them to task for committing a temporal double standard. But the significant point seems to me to be that the whole enterprise of explaining global boundary conditions is suspect, for precisely the reasons Hume and Kant taught us, namely, that we can't obtain causal or probabilistic explanations of why the boundary conditions are what they are. And if that is right, then the important problem is still the traditional one, one immune to Price's basic dilemma.

The Temporal Asymmetry Objection

In Chapters 8 and 9 Price launches a very ambitious project about time symmetry and QM. What would (or should?) QM look like if the founding fathers of the theory adopted the atemporal viewpoint advocated in *Time's Arrow?* In pursuing his goal he launches the 'temporal asymmetry objection' against standard quantum theory (pp. 206-9). Measurements, according to the *standard interpretation* of QM, are time asymmetric. If we make a position measurement on the superposition $|x_1 + |x_2$ and collapse the state to (say) $|x_2$ at t, then for times *after* t, but not *before,* the state $|x_2$ evolves according to the Schrödinger equation. Price asks what justification there is for this asymmetry. He finds that the asymmetry is neither of thermodynamic nor of anthropocentric origin and views this as a genuine difficulty. But what is the problem? This temporal asymmetry is simply the well-known asymmetry of the Projection Postulate in the orthodox interpretation of QM. According to this interpretation the Projection Postulate must be regarded as a *law of nature.* While granting that there are time symmetric alternatives to this, I still wonder what Price has in mind when he deems this a problem. Does he believe there are *epistemic* reasons for believing that the world *must* (*a priori*) have temporally symmetric laws? Elsewhere he talks as though he does: when he states that Penrose must have good reasons for preferring his time asymmetric fundamental law to time symmetric fundamental laws (p. 94). If so, this seems a terribly strong claim to sustain.

Who Is Guilty of 'μInnocence'?

I find the argument of Chapter 5 unconvincing. Price begins by claiming that there are conflicting *intuitions* in contemporary physics. The conflict is supposed to exist between the alleged time symmetry of the laws of physics and the idea—called "μInnocence"—that interacting particles exhibit postinteractive but not preinteractive correlations. μInnocence is said to enjoy "almost unchallenged status" in physics (p. 122). Like Hutchison (see his contribution to this symposium), I believe μInnocence may be a straw man for I do not find this principle in physics. The TRI and determinism of classical physics imply that there are as many preinteractive as postinteractive correlations between particles. The TRI and determinism of the Schrödinger equation in QM imply the same, except according to ('collapse') interpretations that interrupt the Schrödinger evolution. But according to the latter interpretations, there exists a non-TRI law of nature, for example, the Projection Postulate. So where is the conflict? μInnocence is either true due to the existence of non-TRI basic laws or it is false due to the TRI of the laws. The man in the street may like to believe in TRI laws and μInnocence, but his desire does not reveal any confusion *within physics*. The man in the street affirming μInnocence about classical physics (for instance) is simply wrong.

Given my suspicion that physics doesn't hold μInnocence except when justified by a time asymmetric law, Price's next claim comes as quite a surprise. He declares that QM is the sort of theory we *ought to have expected* if we rejected μInnocence (p. 124). He understands QM plus μInnocence to give rise to all of the puzzles commonly associated with QM, such as nonlocality, indeterminacy, and so on (p. 126). Retraction of μInnocence is viewed as a general panacea for all the ills of a quantum world. But this is not right, for retraction of μInnocence says nothing about the notorious measurement problem. The measurement problem arises from the suppositions (1) that the wavefunction of QM offers a complete description of all the properties in the world, (2) that it always evolves according to the linear Schrödinger equation and (3) that we see definite (not superposed) properties. If one holds these three (inconsistent) propositions, one shares the problem Schrödinger exhibited with his famous cat. This is true regardless of whether or not one holds μInnocence.

Price wants to undermine Bell's Theorem by denying the temporally asymmetric assumption known as 'independence' and claiming that hidden parameters in the future may determine the results of our present measurements. He asserts that the rejection of μInnocence helps us to see this possibility. This suggests that Price denies proposition (1). Fine. But it is further incumbent upon those denying (1) to tell us what 'completes' QM. Are there particles (as in Bohm's theory) or something else (as in the modal interpretation)? Price doesn't say, nor is a 'relatively trivial' answer implied from a denial of μInnocence, contrary to what Price claims (p. 126). It strikes me as unfair to those labouring with this hard problem in the foundations of QM to suggest that all the difficulties disappear by denying a principle I'm not sure anyone holds.

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By Keith Hutchison

PEOPLE interested in understanding physics have often been puzzled at the fact that the temporal asymmetries so familiar in the world of everyday experience do not seem to present themselves in the deepest layers of reality—for (with some extremely minor exceptions) what seem to