Review of Ilya Prigogine, *The End of Certainty* (Free Press/Simon and Schuster, 1997) and Derek York, *In Search of Lost Time* (IOP Publishing, 1997), for *Nature,* 6.11.1997, 42.

No Direction Known

Can physics explain the difference between past and future? The laws of physics seem to be time-symmetric. If they allow a process with one temporal orientation, they allow it in reverse. Yet many ordinary pro–cesses seem to be irreversible. Ilya Prigogine calls this the time paradox, and argues that the solution lies in chaos theory, and related methods pioneered by himself and his Brussells colleagues—a radical alternative, he thinks, to a tradition dating from Boltzmann.

Prigogine paints with a rather broad brush. For example, he seems to equate explaining the thermodynamic asymmetry with finding a physical basis for the apparent flow of time. But these are surely diff–erent issues. Someone who treats spatialises time, denying that there is objective flow, will still acknowledge that the universe is asymmetric along its temporal axis, in the way described by the Second Law. If Prigogine's methods do explain thermodynamic irreversibility, they sim–ply account for this asymmetry—they don't give us objective flow.

Leaving flow to one side, what is it that needs to be explained in thermodynamics? Ordinarily we say that it is the fact that entropy *increases*, but we need to be careful here. Whether entropy is increasing or decreasing depends on which we take to be the "positive" direction of time. Reverse the scale on the graph, and an increase becomes a decrease.

Is one choice of scale *objectively* the right one? Is what we call the future *objectively* the sense of "positive" time? If so, this objective fact must consist in something other than the thermodynamic asymmetry itself. Otherwise, asking why entropy increases would be much like asking why a snake's head is at the front end: it would be true more or less by definition.

So there's a dilemma for Prigogine. Either he needs to pull two rabbits out of the hat, one to account for the objective direction of time itself, and another to account for the thermodynamic asymmetry. Or the puzzle about irreversibility isn't what he thinks it is. It isn't that entropy increases *per se*, but rather that it increases in one direction and decreases in the other. (Compare: The real puzzle about snakes is that the two ends are different.)

In the latter case, Prigogine's methods are being applied to the wrong task, I think. He suggests that the sensitivity of chaotic systems to initial conditions introduces unpredictability into physics, and hence explains why entropy is bound to increase. But the sensitivity applies whether we start with (what we call) initial conditions and work "forwards", or start with final conditions and work "backwards". The more chaos helps to convince us that entropy *increase* is inevitable in one direction, the more it ought to amaze us that we see *decrease* in the other direction (a fact which surely ought to give us pause about the reliability of the

"explanation" in the former case: How good is a method which gets things *so* wrong in one case out of a possible two?)

Boltzmann came this way in 1877, noting that it was a consequence of his new statistical methods that entropy ought to be higher in the past, as well as in the future. The real "time paradox" is that entropy goes down in one direction, not that it goes up in the other. Boltzmann may not have had a satisfactory solution, but—unlike Prigogine, I think—he certainly saw the significance of the problem.

In sum, it is one thing to ask how matter behaves when far from equilibrium, another to ask how it comes to be far from equilibrium in the first place. Prigogine has made a lasting contribution to our understanding of the first problem, but the second is the more crucial to an understanding of the difference between past and future. Here, Prigogine's campaign against Boltzmann seems counterproductive. One of the hardest things in this area is to keep the target clearly in view, and Prigogine's new book does little to point us in the right direction.

In Derek York's book, lack of a clear direction turns out to be an advantage. The book is an engaging ramble through diverse topics temporal, by a man who's been dating for forty years, and seems to have loved every minute of it. Recommended.

Huw Price.