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A New Look at Popper's Pond

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In a famous letter to the journal *Nature* Karl Popper argued that wave phenomena exhibit a temporal asymmetry distinct from the thermodynamic asymmetry that entropy never decreases (Popper 1956a). Popper illustrates this asymmetry through the following example. After a stone is thrown into a large body of water whose surface was initially still, circular waves diverge from the point of impact. The time-reversed phenomenon of circularly converging waves — imagine a film showing the diverging wave run backwards — does not occur. This asymmetry raises two questions. First, the fundamental equation governing wave phenomena is time-symmetric. Where, then, does the asymmetry come from? And second, even if the wave asymmetry is indeed distinct from the thermodynamic asymmetry, are the two asymmetries in any way related?

Often Popper is taken to have argued that the answer to the second question is 'yes'. For example, Huw Price argues in his book *Time's Arrow and Archimedes' Point* (Price 1996) that Popper believed that both the wave asymmetry and the thermodynamic asymmetry share a common origin. That is, on the view Price attributes to Popper, neither of the two temporal arrows is reducible to the other, yet both can be explained in terms of a third, cosmological asymmetry. In this paper I will sketch what I take to be Popper's view on the asymmetry, which he presented in his letter to *Nature* and in replies to a series of responses to the letter in the same journal (Popper 1956b, 1957, 1958), and argue that this standard interpretation is mistaken. My motivation in this paper is more than merely to contribute to the project of Popper-exegesis. The view Popper advocates — which might also have been the view of Albert Einstein, whom Popper cites — has virtually no adherents among experts writing on the subject today. This, I believe, is unfortunate since it is in fact the most satisfactory account of the wave asymmetry.[1]

I shall first briefly summarize important features of the physics of the thermodynamic and wave asymmetries and shall then present what I take to be Popper's account of the latter asymmetry.

The thermodynamic arrow is today commonly explained by an appeal to a *de facto* asymmetry between initial and final conditions. Standard microphysical arguments seem to show that any relatively low entropy state evolves with overwhelming probability into a state of higher entropy. But since the

[1] For a detailed defence of this view, see Frisch (2005), Chapter 7.

underlying microphysical laws are time-symmetric, the same argument also appears to show that a low entropy state evolved from a higher entropy past, contrary to what is the case. This symmetry is broken by postulating as initial conditions at the beginning of the universe an extremely low entropy state (and hence, intuitively, an extremely improbable state). According to Price, Popper's account of the wave asymmetry proceeds similarly: In the light of time-symmetric laws the asymmetry of wave phenomena is explained by an appeal to time-asymmetric de facto initial conditions. Some such account of the wave asymmetry has in fact become the received view: most physicists and philosophers writing on the subject argue that the asymmetry needs to appeal to either statistical or even thermodynamical considerations of some sort.

What then does physics tell us about the wave asymmetry? The wave equation used to represent wave phenomena is a differential equation that can be solved either in terms of an initial or a final value problem. More specifically, the equation allows us to determine a wave in a certain region, given the wave at an initial time together with the trajectories of all wave sources in that region, or equivalently given the wave at a final time together with the trajectories of sources. If the wave is represented in terms of an initial value problem, then the waves mathematically associated with each wave source are diverging waves (or so-called *retarded waves*). The total wave is given by these diverging waves together with the incoming wave. If, however, the wave is represented in terms of a final value problem the waves mathematically associated with each source are converging (or *advanced*) waves. The total wave, again, is obtained by adding the wave associated with sources to any source-free outgoing wave. It is important to stress that it is one and the very same wave that can be represented either as a combination of diverging and source-free incoming waves or a combination of converging and source-free outgoing waves. Of course this means that the diverging waves in one representation have to be written as a combination of converging and free waves in the other and vice versa.

So far the mathematical representations of waves in the presence of wave sources, or wave generators, are completely symmetric. Whether the wave associated with an individual generator is diverging or converging merely depends on whether we choose to represent the wave in terms of an initial or a final value problem. In what sense, then, are wave phenomena asymmetric? They are asymmetric in that the total wave often can be represented entirely as a sum of diverging waves with zero incoming waves (such as the wave produced by a stone on a pond whose surface is initially still), but there are (almost) no circumstances where the total wave is fully converging with zero outgoing waves. That is, the wave asymmetry is an asymmetry between prevailing initial and final conditions: Initial conditions can usually be chosen to involve zero incoming waves, but final conditions cannot be so chosen. The problem of the wave asymmetry, then, is to account for this asymmetry in

Now, we can see immediately that the proposal Price attributes to Popper is problematic. According to that proposal the *explanation* of the asymmetry invokes asymmetric initial conditions. But, as we have just seen, the *explanandum* in the case of the wave asymmetry (unlike the thermodynamic case) involves just such an asymmetry. So merely stating that initial conditions are asymmetric is in danger of begging the question. Nevertheless, there might appear to be some evidence in favour of Price's reading of Popper. Thus, Popper emphasizes that the asymmetry is not 'implied by the fundamental equations' of the theory (Popper 1956a). And there is Popper's reference in (Popper 1956b) to Albert Einstein, who, as Price quotes, in one place said that the irreversibility of wave phenomena is not lawful but is 'exclusively based on reasons of probability' (Ritz & Einstein 1909, p. 324).

Nevertheless, it seems to me that Price is misinterpreting Popper's view. For Popper draws a clear contrast between wave phenomena and thermodynamics. While he takes the former to show that 'irreversible classical [that is, non-statistical] processes exist', he says that 'on the other hand, in statistical mechanics all processes are in principle reversible, even if the reversion is highly improbable' (Popper 1956a). Thus, for Popper there is a crucial difference between the two asymmetries: the wave asymmetry is a *strict* asymmetry, while the thermodynamic asymmetry is not. And this difference must be reflected in differences in the explanations of the asymmetries. But how, one might ask, can this be squared with Popper's claim that the asymmetry is not implied by the fundamental equations? How can it be that the wave-asymmetry is strict and at the same time not implied by the fundamental equations governing wave phenomena?

In a later reply to a reply (Popper 1957) Popper distinguishes what he calls 'theoretical reversibility' from 'causal reversibility' and characterizes a radiation process as

> a process that is (*a*) 'theoretically reversible', in the sense that physical theory allows us to specify conditions which would reverse the process, and at the same time (*b*) 'causally irreversible', in the sense that it is causally impossible to realize the required conditions.

That is, while the wave equation is time symmetric and allows for both diverging and converging waves associated with a wave source, converging waves, according to Popper, violate a causal constraint; they are 'causally, and therefore physically, impossible' (Popper 1958, p. 403).

Popper here seems to be appealing to the notion of the wave physically associated with a source: even though the mathematical representation of the wave may change, depending on whether we are dealing with an initial or a final value problem, physically the wave associated with an individual wave generator is a fully divergent wave. The wave physically associated with a wave source is that component of the total wave that would be absent if the source were absent. If this component is fully diverging, then changes to the state of a source have an effect on the wave in the future but not the past

This, then, provides us with an explanation of the wave asymmetry. We find fully diverging waves, but not fully converging waves, since past waves are usually damped or absorbed eventually, so that there are many circumstances in which incoming waves can for practical purposes be set equal to zero. Introducing a wave source then leads to a fully divergent wave.

The notion of the physical contribution of a wave source arguably is a causal notion: sources causally influence the state of the wave medium, and this influence cannot be spelled out entirely in terms of how the wave equation determines the state of the wave, given specific initial or final conditions. The wave equations alone does not tell us how changes to the state of a source would affect the wave. What we need to know in addition is how the initial or final conditions are affected by that change. The causal condition that wave generators physically contribute fully diverging waves partially determine what the correct boundary conditions are: given that sources contribute diverging waves, we know that interventions into the state of the source affect the wave in the future, and hence the final conditions, but not wave in the past and initial conditions.

Thus, we see how wave phenomena can be both theoretically reversible and causally irreversible: On the one hand, as far as the laws of the theory are concerned, which take the form of differential equations and determine how the state of a wave evolves from given initial or final conditions, the theory is completely symmetric. Yet, on the other hand, the physical contribution of each source to the total wave is diverging or fully retarded. Thus, Popper argues that circularly converging waves 'cannot be regarded as a possible classical process', for this (Popper 1956a, p. 538)

> would demand a vast number of distant coherent generators of waves the coordination of which, to be explicable, would have to be shown, in [a film depicting the process] . . . , as originating from the centre. This however, raises precisely the same difficulty again, if we try to reverse the amended film.

And in his second letter (Popper 1956b, p. 382) he adds:

> we are led to an infinite regress, if we do not wish to accept the coherence of the generators as an ultimate and inexplicable conspiracy of causally unrelated conspirators.

Now, Price maintains that Popper took this generator argument as an argument for the asymmetry of the elementary wave processes, instead of assuming the asymmetry as a premise in order to account for the asymmetry of the total waves, as I have suggested. In fact, it is not unequivocally clear from the text whether Popper meant to use the regress argument to *establish* the causal asymmetry or whether he makes use of the claim that there is a causal asymmetry as a *premise* in his argument. But a principle of charity would suggest that we interpret Popper as taking the asymmetry of the individual generators … For Price's criticism of any attempt to argue for the causal … the existence

of coherently oscillating wave generators, producing a converging wave, would constitute an inexplicable conspiracy is to presuppose that the waves associated with generators are fully divergent. For to assume that only divergent waves but not convergent waves (if they were to exist) could be the source of coherent motion is to be guilty of a temporal 'double standard fallacy' (Price 1996, p. 55). If we did not, as I am suggesting, assume from the outset that the generators produce diverging waves, we would have to treat diverging and converging waves on a par and both could account for correlations.

Popper says that converging waves are physically impossible. But should it not be in principle possible to set up coherent generators that produce a concentrically converging wave? Popper argues that such a setup would have to be orchestrated centrally, but this of course does not show that it is strictly impossible. I think we can make sense of Popper's views here, if we pay careful attention to the distinction between the total wave and the elementary processes that give rise to that wave. Popper's view appears to be that the *individual* generators of the wave are asymmetric, and this asymmetry indeed is a strict causal asymmetry. The asymmetry of the individual generators can then help to explain the asymmetry of the total wave. The latter asymmetry, however, is not strict as far as local regions are concerned: if we were to set up things carefully enough and rigged up enough generators in the right way, we could produce converging waves. But if we included the generators of the converging wave in the picture, the original asymmetry is again restored: the converging wave is shown to be the result of multiple diverging waves.

Thus Popper's argument for why converging waves do not occur involves an appeal to initial conditions: initial conditions necessary for the existence of converging waves do virtually never obtain. But one should note that the role of initial conditions in this argument is rather different from that in standard arguments for the thermodynamic asymmetry. In the latter case, the asymmetry of entropy flow is accounted for by postulating what are under some standard measure extremely improbable initial conditions. Some have argued that this presents a problem for the standard account, since it has to leave the improbable initial conditions themselves unexplained. But there is no similar problem for Popper's account, since most 'initial' configurations of generators will not lead to coherent converging waves. Thus, while the thermodynamic case relies on an appeal to improbable initial conditions, Popper only needs to assume that very probable initial conditions obtain — initial conditions where the individual generators are not delicately coordinated. Moreover, since the asymmetry in the case of wave phenomena is ultimately explained by an appeal to an asymmetry characterizing the individual wave generators, there need not be any asymmetry between initial and final arrangements of generators.

As a last bit of support for my reading of Popper I want to point out that it fits rather well with Popper's reference to Einstein. Einstein's writings on the issue present an interpretive problem, since he characterized the radiation asymmetry in seemingly contradictory ways on different occasions. But in the passage to which Popper refers, Einstein unequivocally says that elementary radiation processes are asymmetric and that 'the reverse process [that is, that of a spherically converging wave] does not exist as elementary process' (Einstein 1909, p. 819). In fact, Price's support for his own interpretation of Popper seems to rest partly on getting Popper's reference to Einstein wrong, since Price mistakenly thinks Popper is referring to the joint paper (1909) with Ritz in which Einstein claims that 'the irreversibility is exclusively based on reasons of probability'.

I have presented what I take to be the best possible coherent interpretation of Popper's view on radiation. But I want to end with presenting a certain problem for my interpretation of Popper (or perhaps a problem for the internal coherence of Popper's views). For Popper's own views on the methodology of science do not appear to leave any room for his distinction between what is *theoretically* and what is *causally* possible. For in Popper (1935), § 12, he maintains that

> [t]o give a *causal explanation* of an event means to deduce a statement which describes it, using as premises of the deduction one or more *universal laws*, together with certain singular statements, the *initial conditions*.

And further down he says (ibidem):

> The 'principle of causality' is the assertion that any event whatsoever *can* be causally explained — that it *can* be deductively predicted.

Thus, Popper's own view does not allow for a distinction between what follows nomically from certain initial conditions and what is causally possible. In the case of wave phenomena the wave equation allow us to predict what, in the light of specific initial or final conditions is physically possible. And Popper tells us that making this kind of prediction simply is what we mean by explaining an event causally. But then it becomes a mystery how wave processes can be theoretically reversible in that they are describable both in terms of an initial and a final value problem with the help of time symmetric laws, *and at the same time* can be causally irreversible. There simply is no asymmetry of deductive prediction for wave phenomena.

In this debate between Popper the methodologist and Popper the philosopher of physics I suggest we should side with the latter. In fact, I want to suggest that Popper's views on the wave asymmetry show much more finely honed scientific intuitions than his general methodological writings sometimes seem to indicate.

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