Reversibility reconsidered – a role for history

Abstract:

An old problem concerning the nature of time is how the reversibility of the fundamental, physical equations can be reconciled with the irreversibility in the macroscopic world. The most common solution was first given by Ludwig Boltzmann: While the laws are in fact reversible, the irreversibility enters through the boundary conditions determining initial and final state of a physical system. On the basis of the underdetermination thesis it is argued that there exists no objective distinction between law-like statements and boundary conditions. It can be drawn only by convention. Then, the puzzle regarding the origin of the astonishing reversibility of the fundamental laws cannot be solved by an empirical study of the world alone. Clues should also be provided by looking at the types of problems and applications that have shaped the conventional elements of modern physics. It is sketched shortly, what answers such an historical study might reveal.

At least since the times of Ludwig Boltzmann physicists and philosophers alike have tried to reconcile two facts about the physical nature of time. First, the ubiquitous every-day experience that time is directed: Glass shatters irreversibly. Heat is transferred from the warmer to the colder body irreversibly. Many phenomenological theories naturally incorporate such an 'arrow of time'. Second, all or almost all microscopic equations are reversible. The fundamental physical theories seem to deny completely, that something like an arrow of time exists.

Basically, this dilemma has been approached from two perspectives: (1) One group has accepted the fundamental reversibility of the world as a fact and has tried to explain, how the irreversible world of our experience can arise from a reversible basis. Ludwig Boltzmann himself and Albert Einstein have defended this view, for example. (2) Others have questioned the second statement and have explicitly searched for irreversibility in the fundamental equations. Max Planck at least during one period in his life has taken this stand or more recently Ilya Prigogine.

Proponents of the thesis that the world is in principle reversible explain the observed macroscopic irreversibility by pointing to the boundary conditions. According to their view, physical systems exhibit irreversibility, when they evolve from a very improbable state to a very probable state. So, irreversibility is observed when the initial conditions determine a state that is much less probable than the state determined by the final conditions. This explanation of irreversibility has been put forward by Boltzmann already and was endorsed with some variations by almost all proponents of a fundamentally reversible world, among them Albert Einstein.

Obviously, this solution to the irreversibility dilemma relies on a sharp distinction between (reversible) fundamental laws and boundary conditions (adding irreversibility). In my presentation, on the basis of the underdetermination thesis of physical theories I want to challenge that such a distinction exists as an objective fact – notwithstanding that it has been taken for granted in almost all of the debates concerning irreversibility. My point of view does not imply, that there is no meaningful way in drawing this line. It is just not derivable from empirical data alone. Rather, the distinction is determined as a well-chosen convention, that has proven efficient and successful in the past. Then the reversibility of the fundamental equations is also not a fundamental fact about the world, but owes to conventional elements as well.

An extended abstract is too short to make such an argument entirely convincing. Instead, I want to try to make it plausible by analogy. There is another distinction between statements about the world, which is closely related to that between laws and boundary conditions and which has received much more attention in the literature: the distinction between analytic and synthetic statements. Quine has famously argued in *Two dogmas of empiricism*, that between the latter a clear line cannot be drawn.

Now, law-like statements share with analytic statements the claim, that they always hold – independently of the circumstances. Similarly, synthetic statements share with boundary conditions their dependence on the specific empirical situation. This suggests, that much the same conclusions that Quine has drawn for the synthetic/analytic distinction can also be derived for the distinction between laws and boundary conditions.

There is also a lot of historical evidence, that the distinction between laws and boundary conditions does indeed depend on the respective paradigm endorsed by the contemporary practice of physicists and thus partly on conventions. Just three examples: (1) While for Kepler and many others of his time and before the orbits of the planets were determined by physical laws, in Newton's physics the respective radii are only contingent boundary conditions. (2) The status of several fundamental constants in physics is still disputed. While for some their value is fixed by law, others allow them to change over time. (3) In Aristotelian physics, irreversibility was explicitly incorporated in the laws of movement: every movement is directed towards its natural state of rest. On the contrary, in modern physics irreversibility is commonly thought to originate in the boundary conditions.

If the reversibility of the fundamental equations is just a well-chosen convention, then automatically the question arises, for what purpose this convention is well-chosen. The purpose of empirical theories must of course always be sought in their specific applications. It is then plausible that the origin of the reversibility of the fundamental equations is linked with the specific type of problems that have shaped modern physics. Thus, my somewhat tentative and speculative suggestion is that a historical investigation into the origins of modern physics can at least partly answer the question, why the fundamental basis of physics is reversible.

A striking feature of most problems that early modern physics dealt with, was the restriction to the interaction of two bodies – from Galilei's study of a body falling under the gravitational influence of the earth and Newton's astronomical considerations concerning the interaction between a single planet and the sun up to Coulomb's and Ampère's fundamental laws from the early days of electrodynamics. Apparently, there is no reason intrinsic to reality for such a restriction except the fact that this kind of problems seems to be easily understandable and mathematically solvable. On the contrary, no real-world problems fully correspond to such two-body problems.

There are two fundamental features of physics, that seem especially well adjusted for this kind of problems: the principle of equality of action and reaction and the conservation laws of momentum and energy. Dealing with two interacting bodies it is natural to assume, that none of them can be singled out and both are on an equal footing. With a proper convention of what one understands by action, from this follows immediately the equality of action and reaction. This argument can already be found in Mach's *Science of Mechanics*. Similarly, with a suitable convention of what one understands by action and force, the conservation laws of momentum and energy for an isolated system result.

That there are considerable conventional elements in these fundamental features of physical theory was worked out in particular by Henri Poincaré (see for example his *Science and Hypothesis*). This analysis was agreed upon by many philosophically minded physicists of his time – among them Albert Einstein, Ernst Mach, Hermann von Helmholtz and Pierre Duhem.

Finally, the reversibility of the fundamental equations heavily relies on both of the features just mentioned. For example, that the force-free movement of a single particle is reversible, is guaranteed by the conservation of momentum. Also, that the interaction of two particles is reversible, is closely linked with the equality of action and reaction.

It seems, that the reversibility of the fundamental equations can in part be traced back to the early physicists' preference for two-body problems. Perhaps better established is another conclusion from my presentation: The puzzle concerning the surprising reversibility of the fundamental equations of physics cannot be solved by a purely empirical study of the physical facts, but must also take into account the particular perspective that physics takes on the world.