Causal Classical Physics in Time Symmetric Quantum Mechanics †

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Abstract: The letter submitted is an executive summary of our previous paper. To solve the Einstein Podolsky Rosen “paradox” the two boundary quantum mechanics is taken as self consistent interpretation of quantum dynamics. The difficulty with this interpretation is to reconcile it with classical physics. To avoid macroscopic backward causation two “corresponding transition rules” are formulated which specify needed properties of macroscopic observations and manipulations. The apparent classical causal decision tree requires to understand the classically unchosen options. They are taken to occur with an “incomplete knowledge” of the boundary states typically in macroscopic considerations. The precise boundary conditions with given phases then select the actual measured path and this selection is mistaken to happen at the time of measurement. The apparent time direction of the decision tree originates in an assumed relative proximity to the initial state. Only the far away final state allows for classically distinct options to be selected from. Cosmologically the picture could correspond to a big bang initial and a hugely extended final state scenario. It is speculated that it might also hold for a big bang/big crunch world. If this would be the case the Born probability postulate could find a natural explanation if we coexist in the expanding and the correlated CPT conjugate contracting world.

Keywords: two boundary interpretations of quantum mechanics; time symmetry; causality in classical physics

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What we know is Quantum Dynamics (called Bra-ket physics) establishing stable states and describing matrix elements between an initial state and a final state or analogous matrix elements in Quantum Field Theory at a given scale. An unprecedented precision (sometimes with ten digits) makes the theory most dependable.

Measurements, however, present a problem. Available concepts are not part of a well tested theory. As pointed out a century ago by Einstein, Podolsky and Rosen there is a paradox [1] which needs to be resolved (It is by no means esoteric, p.e. [2,3]). However this is not a problem of underlying Quantum Dynamics but of the interface between Quantum Dynamics and Macroscopic Physics. Hence there are two ways to resolve it. One can either amend or adjust Quantum Dynamics or classical macroscopic concepts.

Considerable effort was invested in the first option. The Copenhagen interpretation [4] of Quantum Mechanics involving quantum jumps and a limited ontology of waves of fields is reasonable but ugly. Penrose [5] is probably correct to speculate that the Hidden Variable [6,7] and the Guiding Fields [8–10] approaches do not work. New experiments involving quantum interferences under
gravitation [11] seem to exclude decoherence by gravitation [5]. Deterministic approaches like the “Cellular Automaton” advocated by ’t Hooft [7] somehow lack motivation as they also lead to similar complications as the ones discussed below.

We here search for a solution in the second approach. The paradigm [12] is to take the wave functions as real ontological objects following well established quantum dynamics and to consider classical physics just as effectively valid. Aspects of the causal macroscopic picture—we accepted a long time ago as well known—might actually not be true on a fundamental level. The huge body of observations could just be a good approximation somehow reflecting our particular cosmological situation.

We do not see a way to describe the multi-faced evolution of the cosmos in a meaningful mathematical framework. The picture presented below is therefore largely limited to intuitive arguments. It develops needed rules and somewhat daring concepts of required mechanisms envisioned to recapture our macroscopic concepts.

With real ontological wave functions the Einstein Podolsky Rosen paradox means instantaneous action over a large distance. Contrary to lore it does not violate the essence of special relativity which just prescribes boost transformations (Our hope is that following ’t Hooft [13] that general relativity can be formulated in a unitary way even around singular structures like black holes and that following Donoghue [14] in absense of of quantum jumps quantum field theory can be implemented in general relativity involving integrals over products of fields. That coexisting paths may lead to different final gravitational field configurations presents no problem for the argument given below). However, using relativity instantaneous action means backward causation in a different Lorentz system [15] which is widely considered unacceptable.

However it is not as bad as it looks. Quantum dynamics contains no time arrow [16] and backward causation is not unacceptable.

The usual interpretation of quantum mechanics involves a fixed initial and asymmetrically an open final state and quantum jumps. The original initial state can, say, evolve to a state containing an electron with sideways (say right) spin. If a Stern Gerlach like measurement finds an upward spin the original initial state is then replaced by the new one in a non unitary, non time symmetric jump:

\[
\langle \text{initial} | \text{Measurement} | \text{Projection} | \text{final} \rangle / \langle \text{initial} | \text{Projection} | \text{final} \rangle
\]

The central point is that in a theory with backward causation the measurement outcome like the up/down decision can just as well be done at a later time then fixing the observed earlier observation.

\[
\langle \text{initial} | U_1 \text{Projection} U_2 | \text{initial} \rangle \leq \langle \text{initial} | U_1 U_2 \text{Projection'} | \text{final} \rangle
\]

For this the measurement must involve sufficient witnesses so that the projected state can be identified later on with a suitable new Projection’-operator even if many projections are involved. It allows to apply a two boundary picture where the decision is made by a final state encoding all the measurement decisions. As for the jump formalism the unitary quantum dynamics evolution has to be amended. One writes:

\[
\langle \text{initial} | U_1 \text{Projection} U_2 | \text{final} \rangle / \langle \text{initial} | U_1 U_2 | \text{final} \rangle
\]

to obtain a unit total probability. This two boundary formalism is well developed by Aharonov and coworkers [17] and others. We stress that this is not a new theory which replaces the old one in a tricky way which would require extensive work presumably of a group of people. The formalism just uses the well established Quantum Dynamics extended it in a straigh forward way.
In contrast to the quantum world macroscopic considerations do not allow for distinct coexisting 
path ways. A large number of effective measurements [18] must reduce ambiguities to allow for a 
macroscopic description. In the two boundary description these measurements must stored in the final 
boundary. This means that the overlap 

\[ \langle \text{initial} | \text{final} \rangle \sim 0.5^{\text{decisions}} \]

must be tiny which is possible. As also claimed by Aharonov and Cohen [19] it is a self consistent, 
time symmetric interpretation of quantum theory.

The difficulty is to understand how the causal classical physics can arise in such a frame 
work. To proceed we introduce two transition rules which prohibit simple backward causation in 
classical physics.

The first one is known as no ‘post selection’ with macroscopic devices. Consider a single photon 
state moving forward in a fiber. It is possible to split the fiber in two and join it again with a 
macroscopically prearranged relative phase. The forward going channel can be prohibited but this will 
not affect the initial creation probability. As a consequence of unitarity other channels (like reflection) 
have to open up.

The second rule states that states produced in a macroscopic distance have a random relative 
phase. To explain the rule we consider a situation where it is violated (for similar consideration see [20]). 
Figure 1 considers two antennas in the focal points of an ellipsoid mirror. Within the antennae clocked 
electronics allows to create preselected situations. With a certain probability one emits a radio frequency 
photon at \(-\Delta T\) which is than absorbed at the other antenna at \(+\Delta T\). If now both antennae emit at 
\(-\Delta T\) and absorb at \(+\Delta T\) in a symmetric way the probability is not effected. However if at \(t = 0\) 
the mirror gets dark on a point of positive interference the initial emission probability at \(-\Delta T\) is 
enhanced. This second order interference effect actually constitutes a violation of the second rule. 
The argument for the rule is that emissions with a synchronized phases and absorptions not averaging 
out enhancements and depletions are extremely rare in macroscopic situations and can therefore 
be ignored.

\[ \text{Figure 1. Second order interference.} \]

In classical physics there is a causal decision tree. At each branching time a decision how the future 
evolves is made. The critical point in the considered framework is to understand the unchosen options. 
In a macroscopic consideration the quantum phases are averaged out. With the resulting “incomplete 
macroscopic knowledge” of the boundary states many path ways can appear if the distance between 
the boundaries is sufficiently extended.

The apparent time direction of the decision tree originates in an assumed relative proximity to the 
initial state (big bang). Given the initial and present macroscopic state in all details there is even with 
incomplete macroscopic knowledge only one path possible. It is not easy for macroscopically different 
states with lots of witnesses to reach the same final state. Only the assumed really distant final state 
allows for multiple chosen and unchosen options.

If now the exact boundary conditions with their given phases are implemented the actually taken 
path is determined. In a classical consideration this selection is mistaken to happen at the instant of 
measurement. So it appears that present decisions affects the choice of the future path.
The expanding universe is source of the thermodynamic arrow [21]. In a closed box all intermediate histories will eventually reach a final state. However, the hugely extended final state of our cosmos and significant effectively interaction less regions make it plausible that all of today’s macroscopic decisions can be encoded there. So the expansion is also source of the effective time arrow considered here. Of course this is just a conjecture. Many aspects of cosmology are not well known and it is not clear that in the limit of a large final time the final state grows faster then needed for the decision tree.

In a symmetric scenario with a big bang and a big crunch [22,23] it might be enough to have an extremely extended intermediate state at the turning point. If the initial and final state are identical any selection collapses as all matching paths contribute and no macroscopic aspects appear. If they are almost orthogonal both forward and backward evolutions will produce two distinct extremely entangled intermediate states. It is conceivable that considering the extreme extent of the intermediate state the entanglement rarely matches and that effectively only one intermediate state contributes.

The unfixed final state opens an amusing possibility. We consider the situation with an electron wave the time \( t \) in the forward moving world (\( t < \frac{1}{2} T_{\text{crunch}} \)) with spin in the rightward direction at and an identical one at \( T_{\text{crunch}} - t \) in the opposite moving one. A component \( \langle \text{rightward} | \text{upward} \rangle \) leads to an upward intermediate state. We assume this state then to be sufficiently traced in witnesses. The component which reaches the same intermediate state in the backward moving world has the same magnitude \( \langle \text{rightward} | \text{upward} \rangle_{CPT} \). Given the witnesses the common final state allows for no mixed contributions. In both cases the remaining evolution should happen if a spin is chosen with unity if the normalization for this case is taken into account. The probability of an upward spin is therefore

\[
P(\text{sideward} \rightarrow \text{upward}) = |\langle \text{sideward} | \text{upward} \rangle|^2
\]

and the Born rule is no longer a postulate but a consequence of the concept.

The seemingly statistical choice is no longer stored in a know-all final state but in an intricate miss match of both “initial” states. The overlap is

\[
\langle \text{bang} | U(T_i, t) p_{\text{up}} U(t, T_{\text{match}}) p_{\text{match}} U(T_{\text{match}}, T_{\text{crunch}} - t) U(T_{\text{crunch}} - t, T_{\text{crunch}}) | \text{crunch} \rangle
\]

for the upward measurement. A corresponding expression holds for the downward one. We consider now for both cases the central second line for the considered case of \( p_{\text{match}} = 1 \). Their values are tiny, say \( 10^{-\text{huge}} \) resp. \( 10^{-\text{huge}'} \). With 50% the value \( \text{huge} \) is “würfelt” (Einstein’s term for dice) larger. The natural statistical variation is of the order \( 10^{-\sqrt{\text{huge} + \text{huge}'}} \). Given its size this will always lead to an exclusive dominance of one choice as the normalization needed in the two boundary formalism is only applied after summation.

In such a scenario objects would exist with their wave function in the forward moving world and with their conjugate function eons apart in tidily correlated opposite moving one.

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