Asymmetry of Time Symmetries

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Abstract

Predictability can be broken down into well defined pieces within physics except for two words: "Before" and "After". Through the usage of a thought experiment, we show how multiple interpretations of time reversal symmetry skews our understanding of how "Before" and "After" are to be understood. These two interpretations are used heavily throughout physics but find themselves constantly at odds when explaining reality. In this short essay, we will showcase each area of physics that utilizes the interpretations and likewise why the two often dispute each other.

1 Introduction

Take a moment to picture a simple particle interaction. Perhaps two Fermions into one Boson or vice versa. Now with this interaction in mind, reverse time to a point just before the interaction takes place. In particle physics terms, apply a time reversal symmetry to the interaction. If you proceed with time moving forward again, what do you see? Most likely it will be one of two things, and which interpretation you saw strictly depends on what you thought when you read the phrase "reverse time". Some may have interpreted the "reverse time" and "apply time reversal symmetry" differently. How is this possible when that is seemingly the same phrase?

Under the first interpretation, you have truly reversed time in which Schwartz tells us particles become antiparticles traveling ***backward in time***[8]; therefore, when time is played forward the process takes place just as it did previously. This may match up with your intuition. After all, we expect decay of processes in our own life to happen in such a way that reversing those processes is equivalent to reversing aging. To some sense we are bound by evolution to this idea of time reversal. We will refer to this process as "cosmic time reversal symmetry" (CTRS)[1] for reasons to be discussed in section two.

The second interpretation of the thought experiment reverses the process (momentums and helicities) ***forward in time*** leading to annihilation via operator processes. "Time playing forward" would be equivalent to setting $t = 0$ and would allow possible final states not seen previously when carried forward.

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[1]Could also be thought of as the treatment of time in the fields of Chemistry or Biology

This is due to the wave function collapsing again after being placed back into superposition. We will refer to the second scenario as "Lagrangian time reversal symmetry" ($\mathcal{L}$TRS)[2] These two modes of thinking produce radically different realities for the time reversal process. On the one hand we have a truly deterministic future which is only certain under the guise of replaying a deterministic past[1]. On the other, we allow all possible states to determine the future as time is merely a coordinate.

Predictability does not have this quality of multiple interpretations. We can break it down into smaller pieces trivially; Take some information, apply a mathematical process to the initial information, and retrieve new information. Simply put, there is a Before and an After (Space before and space after, particles before and particles after, even Energies before and energies after). These terms are all well defined within the constraints of modern physics. Except, Before and After. These two objects are elements of time and rely on information **entered** and information **received** yet are crucial to understanding the predictability of a process. By ignoring the significance of these elements, have we let time become the free parameter that was never actually free, simply implied through our evolutionary perception of causality? The personal interpretation of the aforementioned thought experiment is where the problem takes flight. Time reversal symmetry is needed to relate before to after as well as after to before. These two things should in some sense be the same under this transformation. For most people, how to interpret that reversal is vexing. The second section of this essay will establish the first interpretation of the thought experiment, where time reversal symmetry actually reverses time globally (or under some local "block" in the "Block Universe Theory"). The third section will be the second interpretation, laying down some of the common textbook approaches to time reversal symmetry of Quantum Field Theory. Lastly, we will venture to understand how these different interpretations limit our ability to make predictions, namely testable predictions.

2   Cosmological Time

How old is the universe from the reference of the earth? This is an answerable question[3]. In fact, it is a question that is translatable (and therefore answerable) to other reference frames. As one may venture through the universe, the numerical value associated with this question may change, never the less the definition remains the same. Work is currently being done on understanding the global notion of "Now" [6] regardless of the answer to the posed question. This would only be possible with a global (universal or block-local) definition of time. **Cosmic time** has it's home within the Friedmann-Lemaitre-Roberston-Walker (FLRW) metric and is defined by the time measured by an observer who

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[2]CTRS and $\mathcal{L}$TRS are loosely related to the A and B theories of time in Philosophy. I will avoid this language as I am not fully comfortable in relating the symmetries to the field of philosophy

[3]About 13.8 Billion years

sees the universe expanding uniformly in all directions [7]. This exact expansion is measured by the red shift of distant galaxies as they expand away [11].

One might want to talk about time reversal symmetry under the cosmological time scales. After all, our day to day life progresses under this cosmic time. Instead of the particle interaction that took place in the thought experiment at the opening of this essay, consider your day up until this very moment. Allow the start of your day to be at $t = 0$ and this current point to be $t = t'$. Reverse time to the start of your day, and then play it forward again. If you reverse the "flow" of time that took place throughout the day, your memory of the events will be removed as well, leaving you to recreate your day as the process begins to play out as it had previously. That is to say that defining your state to be $\Psi(t)$, there are definite solutions to the wave function integrated from 0 to t'. However, $\mathcal{L}$TRS of particles making up the day to day routine will not necessarily play out like the previous version since the wave functions would not necessarily need to collapse the same way (§ 3). Statistically, it is not possible to recreate the $\Psi(t')$ since at any other point the process is some $\Psi(t'')$ which has continued evolving under the cosmic time progression. By this definition of time reversal so we see the state $\Psi(t')$ again, would require a true cosmic time reversal [4].

An antagonist of determinism may argue that the reversal of cosmic time followed by replay does not imply that the wave function will collapse as it did the first time. However, the ansatz here is that if you uncollapse a wave function using cosmic time reversal it will collapse the same way again ie. **The indefinite future becomes the definite past**. This is the only guaranteed definition of determinism as the future has already been determined (as the past) and therefore must come to fruition. This is clearly not reproducible in the laboratory.

It is worth mentioning the role gravity can play in these day to day interactions on a large scale as well as a small scale. We have yet to find empirical evidence for a graviton. Reversing cosmic time will have this appearance of oppositely directed classical gravity. The directionality of gravity further complicates the $\mathcal{L}$TRS of gravitons as we don't have a grasp of their underpinnings. Further investigations into quantum gravity may resolve notion.

3   Time Reversal Symmetry in QFT

A basic aspect of Lagrangian quantum mechanics is understanding the symmetries that allow interactions to take place. Amongst the symmetries exist, Charge, Parity, and Time, Time being the most confusing of the symmetries due to this necessity to act on complex numbers as well as on states [3]. This therefore forces $\mathcal{L}$TRS to be **antilinear** and **antiunitary**[5].

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[4]Local vs non-local is not the issue here as Ellis et al. have address this. Instead we refer to the cosmic time reversal of the observer and whatever neighborhood is required as per given treatment.

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Schwartz gives us an excellent example of what happens when we define $\mathcal{L}$TRS the same way as CTRS. Namely, we end up with something that is identical to the inverse CP (charge and parity) invariance and therefore makes the sought after CPT invariance trivial. While there are ideas about CPT invariance being possibly physical, a pioneer in my field of study (parastatistics[5]) Oscar Greenberg has shown [2] that there is a locality condition requiring CPT violation to require violation of Lorentz symmetry, furthering the strength of the CPT invariance requirement for the Lagrangian to be physical. Following this logic we see that our CTRS does not satisfy the requirements of the Lagrangians which have been crafted to explain successfully modern Quantum Field theory.

Matters are made worse because the dimentionality of time as established by Special/General Relativity is necessary to ensure the decay of particles observed by ***following the exact principles listed above (ie. CPT invariance)***[10]. So the theories that bore the FLRW metric (that define cosmic time and contains an intuitive symmetry not compatible with particle physics) are ***necessary*** to produce the very theory they disagree with[6].

As if the problem of reconciling time as a symmetry isn't hard enough, we experience other interactions with this coordinate that may or may not have any physical implications. Take for example Matsubara Green's Function (MGF) [4]. Here lies one major crux of the Symmetry debacle. The MGF takes what would be a traditional time dependent Green's function of many body particle physics and models it as a statistical mechanical problem. It is also a reasonable guise to model the temperature change in the early universe under the rules of statistical mechanics, as temporal change under those same rules [7]. Again two seemingly accurate representations of reality built off of symmetries that we experience both every day and in the laboratory that do not agree.

4   Reconciling Predictability

Once more, we visit the inadequately defined "Before" and "After". Separate interpretations of the thought experiment examined in different forms throughout multiple texts have unsuccessfully clarified how the terms are to be deciphered. Under the CTRS, we have global time reversal to maintain the second law of thermodynamics, and an explanation of how a determined future could exist (strictly tied to a determined past). However, the CTRS forces CPT invariance to be a pointless symmetry. CPT invariance which is deeply connected to both particle statistics and Lorentz invariance gives way to particle interactions that can only exist under a time dimension established by the very theory that make CTRS intuitive and definable. This is problematic. "Before" and "After" are tied up in the skewed relationship of how time progresses through interactions.

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[5]After all, CPT symmetry is connected deeply to particle statistics [9]

[6]This wouldn't be such a problem, if QFT wasn't built upon symmetries to begin with. But, here we are.

[7]The issue is, whether these are physical equivalences or mathematical tools to describe a nonphysical relationship.

This Essay's contents are in no way novel. The conclusions have been issues for some time. However, the emphasis is the requirement of **_understanding how this symmetry is breaking_**. If this leaves you feeling unresolved, it should. With that said, this problem exists as a means to explain the current limits we have reached with testable predictions. One of the two camps will have to break, perhaps both. Time will tell.

References

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