Length Matters (II): Minimal length in (loop) quantum gravity and the fate of Lorentz invariance — a methodological study

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In theoretical physics the success of a theory is often achieved when an interesting body of mathematical results becomes a plausible explanation of natural phenomena. This process usually involves two phases: (1) the theory demonstrates mathematical consistency, and (2) it leads to predictions of phenomena that are both new and generic, i.e., new phenomena that are general consequences of the mathematical formalism and thus hold for a wide range of parameters as well as for generic initial conditions. We usually see the theory as a viable explanation when some of those new generic phenonena are observed.

While mathematical consistency is ultimately necessary, it is not sufficient for the success of the theory. As the history of science shows, the reasons why theories succeed or fail often have to do with their generic consequences. In successful cases the consequences do not stand in conflict with previous experiments but are easily confirmed when searched for in new experiments. In unsuccessful cases the consequences generically disagree with experiment. Some of these 'bad' cases still survive for some time because the theory has parameters that can be fine–tuned to hide the empirical consequences, but ultimately they succumb to lack of predictability (which follows from the same flexibility that allows the generic consequences to be hidden).

During the 'phase transition' from (1) to (2) physicists often come up with heuristic arguments that are sufficient to uncover generic consequences of new theories even before precise predictions can be stated. For philosophers of physics who defy Otto von Bismarcks famous quip ("Laws are like sausages, it is better not to see them being made"), this state of affairs allows an interesting glimpse into the practice of theoretical physics.

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Such an opportunity presents itself today in the domain of high energy physics, where at least one candidate theory for the unification of quantum mechanics and general relativity — loop quantum gravity (LQG) — has reached this transitional stage. In this paper I focus on one of the generic consequences of LQG, namely, the fundamental discreteness of space, and on the lively debate on whether or not this discreteness entails a departure from exact Lorentz invariance. Since current experiments, in the highest energies we can manage, show no sign of departure, LQG theorists are facing an interesting methodological dilemma: on one hand they would like to transcend phase (1) and rebut the old pessimistic argument that says we would never be able to test quantum gravity effects (e.g., Isham 1995); on the other hand they would like to avoid phase (2), as it seems that a generic consequence of the theory leads to some fatal results and contradicts experiments. In recent years a possible way–out from this dilemma has surfaced (e.g., Amelino Camelia 2002; Smolin 2005), which extends the principle of relativity to include a fundamental length scale, and instead of 'breaking' Lorentz invariance, 'deforms' the Lorentz group (hence the name, DSR, for Deformed Special Relativity). Among the challenges DSR faces, two are particularly instructive as they best exemplify the aforementioned dilemma. The aim of the paper is (i) to expose a common feature of these two arguments, and (ii) to draw some general methodological lessons from the similarities they bear to other case–studies in theoretical physics.

I begin by surveying the theoretical considerations that have led to the idea of discreteness of space in theories that aim to unify quantum field theory with gravity (Deser 1957; Wheeler 1957; Mead 1964), and proceed by accepting as a working hypothesis the claim that LQG predicts such a discreteness (Rovelli & Smolin 1995; Rovelli 2004, pp. 249–259; Rovelli 2007). Next I discuss the intuition that (a) the discreteness of space ultimately leads to violations of Lorentz invariance, and the debate that ensues on (b) whether such violations indicate violations of the principle of relativity. I complete the setting of the stage by briefly presenting DSR which accepts (a) and rejects (b). In the main part of the paper I address two heuristic arguments against DSR: the first (Rovelli & Speziale 2003) aims to undermine (a) by arguing for a compatibility between discreteness of length and Lorentz invariance. The second (Schützhold & Unruh 2003) aims to expose the price for a negative answer to (b). The main goal of the paper is to demonstrate that both these arguments are unconvincing as both assume the universal applicability of the principles DSR modifies. Finally, I compare these arguments to other case–studies from the history of physics where a similar methodological flaw is present. The analysis is conducive to the broader project the author has been engaged in (e.g., Hagar 2007), namely, the extraction of metaphysical predilections from the actual practice of theoretical physics.

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