Dynamical calculations regarding Lorentz-contraction and time-dilation

This summer I was working under the supervision of Professor Simon Saunders while taking part in the Merton college summer projects scheme. My project was concerned with different interpretations of Special Relativity (SR). It was specifically aimed at investigating possible ways of offering so-called dynamical explanations for the phenomena of Length-contraction and time-dilation as described by SR.

On the dynamical approach to SR, the phenomena of Lorentz-contraction and time-dilation are taken to be more fundamental than the Lorentz-transformations, which relate spacetime coordinates of different inertial frames of reference. Lorentz-contraction and time-dilation are explained as arising from the form of the fundamental laws of physics, governing the fundamental dynamics of objects such as rigid rids and clocks. The dynamical approach, which is often called the truncated Lorentz pedagogy, is contrasted with the geometrical approach, on which the Lorentz-transformations are claimed to highlight properties of spacetime geometry. On the geometrical view, these spacetime-properties are taken as more fundamental than Lorentz-contraction and time-dilation and to supposedly provide better explanations of SR phenomena than any dynamical argument.

The dynamical/geometrical controversy is not only interesting because it concerns the question of which explanation of SR phenomena should be preferred in theoretical physics. The controversy is also associated with the puzzling question of what exactly is going on in situations where rigid rods and clocks display Lorentz-contraction and time-dilation, which all physics students having learned SR will most likely have asked themselves at some point.

Does the Lorentz-contraction of a rigid rod represent some actual change in its intrinsic properties, or is this phenomenon on the contrary purely the result of perspectival effects? Maybe Lorentz-contraction represents something in between these extremes?

This is another question which the proponents of the different approaches to SR disagree upon. The only way of getting closer to fully answering these kinds of questions is seemingly to provide arguments for or against the dynamical or geometrical view of SR.

During the summer, I produced two essays concerning and supporting the dynamical approach to SR. I investigated possible extensions to sufficiently simply thought-experiments, wherein Lorentz-contraction or time-dilation effects can relatively easily be explained dynamically[1]. In one of the essays, I specifically extend on a thought-experiment first devised by Jefimenko[2], concerning a small charge oscillating inside a charged ring. I was able to show that the oscillations of the small charge will Lorentz-contract and time-dilate in

[1]The explanations of Lorentz-contraction and time-dilation in such thought experiments follow from the dynamical laws governing the systems in question, which in most cases just concern electromagnetism. Such explanations are far from being fundamental dynamical explanations, i.e., explanations build up from the currently most fundamental dynamical theories of physics (like the standard model perhaps). However, constructively explaining SR phenomena from non-fundamental dynamical laws still supports the truncated Lorentz pedagogy in various ways, which I specify in the essays.

[2]Jefimenko O D 1998 'On the experimental proofs of relativistic length contraction and time dilation' *Z. Naturforsch. 53a, 977-982 (1998)*

the limit where the charged ring is being accelerated to a velocity in an infinitely gentle way. This can be shown both when treating the problem within classical mechanics and quantum mechanics (QM), by using various mathematical tricks, such as the classical and quantum adiabatic theorems and the correspondence between simple generating functions in classical mechanics and simple unitary transformation-operators in QM. Of course, my argumentation was not completely fundamental, and had to rely on assumptions about the laws governing the idealized system in question. However, I still consider it a success for the dynamical view that the SR phenomena displayed by the system can be explained dynamically, and in addition, explained completely analytically (with no need for computer simulations).

In my other essay, I investigated a QM model for a system of charged particles, which could represent a rigid rod or clock. I was able to argue, that under various assumptions about the dynamical laws governing the system (electromagnetism) and about the macroscopic properties the system possessed at rest, one can provide a kind of semi-empirical[3] dynamical explanation of Lorentz-contraction or time-dilation for the given rod or clock. Both essays are still being worked on, but it is the hope of me and my supervisor that one, or both, could be published once finished. This is at least something we will be aiming for.

It was a really nice experience to live at Merton and work on the project this summer. Although Oxford was not as lively as usual, due to Covid, I still really liked spending some months of my summer here. I also really appreciated being granted the opportunity to experience what it feels like to work on an academic project you find really interesting. Since most of my work on the project consisted of reading various books and papers, having access to the world-class libraries at Oxford was very important for the quality of the project.

I am thus very appreciative of having received the Merton summer project grant, such that I could live at Merton and focus intensely on my project, parts of which may even end up being published.

Lasse Wolff

[3]S*emi-empirical* because the explanations rely on dynamical properties of the system in question which are just assumed instead of dynamically explained