Quantum Non-Locality and Relativity

By Tim Maudlin

It is sometimes stated that composite quantum systems in entangled states are fundamentally 'non-local'(i.e. a measurement on one component system can affect a space-like separated system 'instantaneously') and therefore, non-relativistic quantum mechanics violates Relativity theory. This conclusion is usually thought to follow directly from Bell's Theorem in quantum mechanics and the upper limit on velocities provided by the speed of light in Relativity. But exactly what if the conflict between the kind of non-locality exhibited by entangled quantum systems and either the Special or General Theory of Relativity? Maudlin's *Quantum Non-Locality and Relativity* is a beautifully crafted book that attempts to answer this question by evaluating four purported restrictions imposed by Relativity. He also considers four attempts to formulate Lorentz invariant quantum theories and concludes that such accounts exact a high philosophical price. Maudlin has achieved his first goal: he gives a lucid exposition of the tension between quantum non-locality and Relativity theory which is accessible to the non-specialist. But *is* there a high philosophical price to be paid for Lorentz invariant quantum theories and can we afford it?

Maudlin sets the stage in the first two chapters by introducing the 'non-locality'of entangled quantum systems and the Special Theory of Relativity respectively. The mysteries of entangled states surface through Maudlin's version of the EPR thought-experiment: two people, who cannot communicate after leaving a common room by opposite doors, are asked questions which correspond to detector settings. The challenge is to construct a strategy for answering the questions that reproduces the behaviour of correlated pairs of photons. Maudlin uses the impossibility of this task to illustrate that the 'quantum connection'is curious because it is unattenuated, discriminating and instantaneous. This chapter also contains an appendix on the Greenberger, Home, Zeilinger (GHZ) thought-experiment which shows that demonstrating non-locality need not involve the complications of a statistical argument. Maudlin's introduction to Special Relativity contains many helpful diagrams and carefully hones the reader's relativistic intuitions by discussing common paradoxes and misunderstandings. For example, the chapter closes by considering various answers (ranging from incorrect to correct) to the question:'What would it be like to travel at 99.99% the speed of light? (p. 57).

Each of the next four chapters is dedicated to one of the four restrictions, often claimed to follow from Relativity, on superluminal mass-energy transfer, signalling, causation and information exchange. Maudlin argues that the Bell inequalities do not entail that there is superluminal mass-energy exchange between the two wings of an EPR type experiment. However the Bell inequalities do entail that, even though we cannot identify which event is the cause and which is the effect, the two wings of the experiment are 'causally implicated'because they satisfy the requisite counterfactuals. So while we cannot say that 'this event superluminally caused that event'we can say that there must have been superluminal causation. Yet, perhaps the most interesting aspect of the book is his discussion of superluminal signalling and superluminal information exchange. How can

Maudlin claim that while there is no superluminal signalling, there *is* superluminal information exchange?

For Maudlin, signalling is an anthropocentric notion that involves a nomic connection between a *controllable* transmitter and an observable of the receiver. Thus, the question of superluminal signalling reduces to: "Can manipulations of the polarizer on one wing of the experiment produce a noticeable effect on the other, given that the Bell inequalities are violated?" (p. 82). The negative answer to this question is well-known:'there is no Bell telephone'. For Maudlin, however, to claim that there is no superluminal signalling is *not* to say that no information flows between the two wings of the experiment. The amount of information exchanged between transmitter and receiver is a measure of how much one can infer about the state of the former from the state of the latter. Notice that information can be exchanged even if we cannot control the information being transmitted. Maudlin's clever calculation shows that the quantum statistics can be reproduced if a pair of photons exchanges, on average, just over 1 bit of information. And as Maudlin himself points out, the systems must be capable of exchanging an infinite amount of information at least some of the time.

Maudlin argues that we can determine how much information is exchanged between the two wings of an EPR type experiment without concerning ourselves with the details of the communication channel. Conspicuously absent from this discussion of the 'studied agnosticism'afforded by the study of information exchange is the claim that information, just like signalling, is anthropocentric. And this may affect our appraisal of 'information exchange'between the two wings of the experiment. When we ask 'how much does a photon need to know …?", we are implicitly assuming that the photon carries a sort of table (viz. that there are 'hidden variables') such that given the information about its distant partner, the photon can change its physical state in the appropriate way so that it is either passed or absorbed. This in turn assumes what Maudlin himself elsewhere criticises: that detectors are entirely passive in the measurement interaction. Also, one wonders how strongly Maudlin's calculation of the amount of information exchange depends on the statistical characteristics of the EPR set up. Could a similar calculation be carried out for the particles in the GHZ thought-experiment? And if so, what would such a result indicate?

After showing that the Bell inequalities entail superluminal causation and superluminal information exchange, Maudlin shows that whether we consider 'collapse'or 'no-collapse' theories, it seems there is a high philosophical price to pay for a Lorentz invariant quantum theory. Under the rubric of 'collapse' theories, Maudlin considers Cramer's transactional interpretation and Fleming's hyperplane dependence interpretation. His exposition of Fleming's view is careful and ensures that non-specialists will not be led astray by talk of systems which differ depending on what hyperplane is considered. However, he leaves the reader with the impression that Fleming's view solves the problem of Lorentz invariance 'by a radical generosity": a given photon can be both in a state of definite polarisation with respect to one hyperplane *and* a state of indefinite polarisation with respect to another hyperplane. But for Fleming, this unlikely and profligate ontology is a *consequence* of his theory and not a premise used to solve the problem. What Maudlin has not told us is why, if Fleming's view is a ‘good’ scientific theory, we should question the theory's metaphysical implications rather than our intuitions.

Since the problem of Lorentz invariance seems linked to wave collapse, are ‘no-collapse’ theories unproblematic? Maudlin considers Bohm's theory and Albert and Loewer's Many Minds interpretation and concludes that these theories are also not Lorentz invariant. Most notably, Maudlin shows how problems with Lorentz invariance get smuggled into Bohm's theory. He points out that a preferred notion of simultaneity is inherited by the Bohm theory through the notion of ‘configuration’. This, I think, is a valuable point that is often overlooked: “Configurations are *configurations at a time*, they specify where all the particles in a system are *at a given moment.* So the very notion of a configuration is not a Lorentz invariant concept” (p. 216). So long as we are employing a ‘classical’ configuration space, attempts to construct a Lorentz invariant theory are doomed to failure. Unfortunately, one is left wondering why Special Relativity can represent configurations of physical systems and still have a Lorentz invariant theory while this seems impossible for the kind of configuration space used by the Bohm theory. Also, are representations of quantum systems in Hilbert space in orthodox quantum mechanics also susceptible to this problem?

The last chapter concludes with a clear introduction to the main tenets of General Relativity and a discussion of the problems encountered by these views in that setting. The book concludes with a brief chapter entitled ‘Morals’ where Maudlin states the main results of his book and concludes: “Quantum Theory and Relativity seem not to directly contradict one another, but neither can they be easily reconciled” (p. 242). Though this is not a particularly ‘novel’ result (it has been implicit in the literature for some time), his book is a valuable contribution to the philosophy of quantum mechanics because it concretely analyses what has become accepted dogma regarding the conflict between quantum non-locality and relativity.

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