Quantum Space-Times: An Introduction to "Algebraic Quantum Mechanics and Pregeometry".

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Abstract. This is an introductory note to the paper, "Algebraic Quantum Mechanics and Pregeometry", written by D.J. Bohm, P.G. Davies and B.J. Hiley in 1982, and previously unpusblished.

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There is now a growing realisation that some of the problems in quantum mechanics seem to have their origins in the deeper meaning of space-time. To date the classical Minkowskian view has dominated physics, but the pioneering work of Wheeler [1] and the advent of string theory, M-branes etc [2]. have accelerated our thinking as to the role space-time plays in the quantum domain. Normally one thinks that these questions are only relevant on the very small scale where it is common to talk about notions such as the fluctuations in the metric tensor. But we should be cautious about limiting our discussions to small space-time distances. For example, quantum entangled states already exhibit non-locality on the macroscopic scale and such a notion is completely foreign to our traditional concepts of space-time with its insistence on a notion of absolute locality. What is called for, in my view, is a radical re-consideration of our views of space-time as a whole and the role it plays in the quantum domain.

This debate is gaining momentum and in this conference Thomas Filk [3] presents a paper raising some of the deep questions that have to be considered. In listening to his presentation I was taken back to the late 70s and 80s when a group of us at Birkbeck College were discussing the implications of the experiments on non-locality being carried out by David Butt, June Lowe and Alan Wilson [4], three of our experimental colleagues. In their pioneering work they had shown for the first time that entanglement persisted even though the resolution time of detectors ensured that the detection events were space-like separated. We were well aware of these results long before their paper was finally published and certainly long before the Aspect results were published [5].

I had been very interested in an algebraic approach using Clifford algebras, particularly as Roger Penrose [6] had introduced me to spinors and twistors. The algebraic approach seemed to capture the essence of quantum mechanics without the need to formulate the whole thing in Hilbert space. I had also been very aware of the pioneering mathematical work of Hamilton, Grassmann and Clifford himself. They argued that the elements of an algebra had a natural interpretation in terms of activity or process; how one aspect of a process turns into another. Their work would enable me to see how the properties of space-time could be carried by an algebra without the need to resort to some underlying manifold containing a Cartesian co-ordinate frame. The algebra itself carried rotational and translational symmetries and even the points of the space itself so it was not necessary to start with the traditional view of an a priori given space-time manifold. Together with the help of a research student Phil Davies, I manage to find a toy model of a quantum phase space using the discrete algebra that I found in Weyl's classic book "The Theory of Groups and Quantum Mechanics."

All of this fitted in very nicely with the notion of the implicate order that David Bohm [7] had been developing at the time. The model illustrated the role played by the uncertainty principle, not as a limitation of our ability to measure a pre-existing position and momentum, but the fact that the very structure of the physical processes themselves did not enable us to construct a single phase space. One could either make the position space explicate or one could make the momentum space explicate, but never both together. (Later, much later, I realised that this was an example of the Manin plane [8].)

This work was very important for me at the time because it highlighted three important factors. Firstly it showed

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that the algebraic aspects of quantum mechanics could ultimately carry implications of its own space-time structure. What was missing was a deeper mathematical structure that could capture more realistic, complex quantum processes. This I believe is now being developed under the general heading “non-commutative geometry” [9]. When the paper was written we were following Wheeler’s lead and called it ‘prespace’.

Secondly it showed how locality could be carried as a relationship. Here the hologram stands out as a metaphor. But the mathematics allows for a new features in which not all aspects of a quantum process can be made local. Thus for the first time we have a way of understanding quantum non-locality in terms of a coherent structure. It does not have to be ‘plastered’ on to a basically local structure. How this ultimately fits in exactly with relativity, both special and general, has still to be worked out. In the meantime I feel the following paper outlines some ideas, which I hope will be of some inspiration for further work.

Finally the ideas gave mathematical structure to Bohm’s notion of the implicate order. This provides the current mathematical work on non-commutative geometry with an intuitive and perhaps more philosophical structure so that one does not have to rely entirely on abstract mathematical ideas.

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