Revealing Quantum Flow

There are no phase space trajectories in quantum physics but that is not the full story. UK-based physicists Ole Steuernagel, Dimitris Kakofengitis and Georg Ritter have found that a new powerful tool they call ‘Wigner flow’ is the quantum analog of phase space flow. Wigner flow provides information for quantum dynamics similar to that gleaned from phase space trajectories in classical physics. Wigner flow can be used for the visualisation of quantum dynamics. Additionally, and perhaps even more importantly, Wigner flow helps with the abstract analysis of quantum dynamics using topological methods.

Understanding a dynamical system can be very hard, in the case of ‘chaotic’ systems prohibitively so. Scientists have therefore developed an arsenal of visualisation tools to glimpse structures which would otherwise be missed. Physicists like to plot systems’ dynamics in an arena they call ‘phase space’. Essentially, phase space uses coordinates suitable for the study of a system’s dynamics. Phase space methods have found applications in fields spanning mechanics, electrical engineering, and population dynamics in ecology.

In phase space, trajectories generated by the systems' dynamics --be they measured, or generated through computer code-- are plotted. Widely known examples are ‘strange attractors’ of chaotic systems such as the well known Lorenz attractor. They illustrate well the power of phase space methods; although there had been hints of the existence of chaotic systems since the late 19th century it was only with modern computers that chaos in dynamical systems became recognized and its study accessible.

In classical physics phase space trajectories give rise to flow-fields representing the dynamics of the system along its trajectories; they yield additional insight into a system's behaviour.

Quantum theory phase space trajectories do not exist because Heisenberg's uncertainty principle does not allow for the formation of sharply defined trajectories. But quantum physicists have not given up entirely on phase space. The study of the next best thing, the movement of quantum physics' phase space-based probability distributions has actually boomed in recent years.

Sophisticated schemes for the reconstruction of the most prominent of these distributions, ‘Wigner’s function’, from experimental data, have set quantum phase space analysis on a firm footing. Yet, since quantum trajectory studies cannot be carried out, some of the power of established classical methods is missing.

Because trajectories are missing in quantum phase space, physicists did not pay much attention to the associated flow-fields, although these do exist. Now, in research published in 'Physical Review Letters', Steuernagel et al., of the University of Hertfordshire, show that quantum phase space flow is well worth studying.

They have been studying Wigner flow, which is based on the dynamics of Wigner’s function, and shown that it reveals new and surprising features of quantum phase space dynamics. It forms, for example, vortices that spin the 'wrong' way round and which appear in the 'wrong' part of phase space, when viewed from a classical physics standpoint. So, such dynamical patterns are manifestations of the quantum nature of the system.

On top of such new riches the team has established the existence of a conservation law that reveals a new type of topological order for quantum dynamics. As an application they have shown that Wigner flow sheds new light on quantum tunnelling, the fundamental process that governs the workings of electronic computer circuits, and also the decay of radio-nuclides.