# Quantum Time

In relativity time and space are formally indistinguishable; the only obvious difference is that they enter the metric with opposite signs.

But in quantum mechanics, time functions as a parameter. Like a butler, it escorts wave functions to and from experiments, but does not itself take part in the action. We can ask what happens if we release this restriction: if we let the butler join the party?

To do this in a well-defined way, we distinguish between time in two senses. The first is laboratory time: what Alice measures with clocks. The second we refer to as quantum time, with properties defined by symmetry with respect to the properties of space.

If we think in terms of wave functions, we can define the three dimensional wave function of a particle at a specific laboratory time. Then we generalize this wave function to four dimensions. At each clock tick, the particle will have an amplitude to be found a bit ahead or behind of its current time. Just as it does not have a well-defined position in space, it will not have a well-defined position in time. To generate the dynamics we use path integrals, which generalize in a relatively straight-forward way from three to four dimensions.

If there are such quantum fluctuations in time, why haven't we seen them? In general, to see quantum mechanical effects in a scattering experiment, both apparatus and beam have to vary in comparable ways: the particle has to have a quantum mechanical width not too much larger or smaller than the slit it is going through, and so on. The same for time. Both beam and apparatus have to have time dependencies of comparable scale, or any effects will be averaged out.

If effects from quantum time normally average out, how do we see them? Almost any existing foundational experiment on quantum mechanics may be turned into a possible test of quantum time by interchanging time and a space dimension. We look at a subset of the possible experiments: particles going through time-varying electromagnetic fields, photons scattering from atoms, diffraction in time, Lindner et al's recent double slit in time experiment, and -- not the least entertaining -- the Aharonov-Bohm experiment in time, where the wave function of a charged particle shows interference effects from a capacitor charged only when the particle is not present.

Quantum time can be seen as an essentially conservative idea: extending standard quantum mechanical techniques to include time. Advantages include: providing higher symmetry between time and space, eliminating ultraviolet divergences in the case of the Lamb shift (as a result of fuzziness in time), and suggesting a large number of foundational experiments. As a result of the first two points, it provides a natural starting point for investigations of quantum gravity. And a negative result in a search for quantum time is likely to identify a preferred frame, itself an interesting result.