QSS26 - Christiane Koch - Questions & Answers

Christiane Koch

Bill Phillips: is there a clear distinction between quantum control and simple manipulation of a quantum system. Is, for example, pi-pulse, or adiabatic passage, or spin (Hahn) echo considered quantum control? I usually call things quantum control when I cannot guess the outcome without doing a calculation

CHRISTIANE: No, there is not a clear dividing line. It is really a matter of taste.

For optimal control applications there are differences between open-loop and closed-loop scenarios - where you either calculate a control field and then use it, or optimise the control field iteratively in an experiment. For which types of applications is closed-loop iteration possible or better, and for which types can you achieve high fidelity to your target state by calculating the control field theretically?

CHRISTIANE: Closed-loop iteration is possible if you can carry out your measurement quickly and repeat the procedure that makes up the feedback loop. Open-loop control works well if you know your Hamiltonian with high accuracy, as was the case in my Rydberg example. Similarly, in NMR or for molecular rotations, we know the Hamiltonian very well. On the other hand, if electronically excited states of molecules are involved, our theoretical models are not sufficiently accurate, so we cannot expect calculated control fields to work immediately in experiment.

Chi Shu: Is there a way to estimate how well the quantum control can reach before fully implementing it? Saying given certain limitation in a system Rabi frequency and other parameters.

CHRISTIANE: That's exactly the point! Provided our Hamiltonian is sufficiently accurate. One of the main applications of quantum control is to identify fundamental limits and performance bounds.

Roman Bause: Around 2005, there was very interesting work on using quantum control to create diatomic molecules such as KRb in the ground state. Shortly afterward, this research seems to have stopped. Was this only because it was no longer necessary due to the successful use of two-photon Raman transitions for the same purpose, or were there other factors involved?

CHRISTIANE: If you want to create the molecules, there is a fundamental problem in that you start out in a continuum state (with very small quantum purity) and you want to reach a pure quantum state. For a coherent process, the efficiency is very limited. If, in contrast, you start out from a weakly bound molecule (created e.g. using magnetic field control of a Feshbach resonance), the situation changes and this could be done with shaped laser pulses.

Bill Phillips: The example you gave about separating different chirality with only an electric field was indeed surprising (at least to me). As you suggested, I was thinking that one would need a magnetic field. But it seems that there should be some kind of general argument involving symmetry that tells whether it works with electric fields only or whether you need magnetic fields as well. Is that indeed the case?

CHRISTIANE: Indeed, you do not need a magnetic field to address different Zeeman sublevels – and that was a surprise to us, too! The reason is that the transition matrix elements depend on m (due to Clebsch-Gordan) and therefore you can distinguish different m. A more general argument goes as follows: What causes the degeneracy is the 3D nature of molecular geometry, and what we use to distinguish degenerate levels is the 3D nature of the light-matter interaction.

Kaloyan Zlatanoff : Are the external energy shifts e.g. from static fields also the same for the two enatiomers?

CHRISTIANE: For randomly oriented molecules, yes! Because the matrix elements are the same (except for the sign change I mentioned).

Bill Phillips: What is a “cat” is often a tricky question. We don’t call a superposition of spin up and spin down a cate, but we would call a superposition of a lot of spins all up with all those spins down a cat if there are enough spins. What is the measure of “cattiness” in your case?

CHRISTIANE: We haven't quantified "cattiness" but the usual argument for the Rydberg manifold identifies many spin-1/2s with one large spin, which is what we have in the ladders that I showed.

For open quantum systems, your example of making use of existing dissipation was very nice. But would control be easier if you had the control without the dissipation? If so, are their types of dissipation that can provide a resource, that make control easier/more effective than in the absence of dissipation?

CHRISTIANE: In this example, it wouldn't work without dissipation. And that's the essence of quantum reservoir engineering - the dissipation is what gives you the unidirectionality of the process. Coherent control alone would drive you all over Hilbert space.

Chin-wen Chou: If an external magnetic field lifts degeneracy among transition frequencies, does that make the problem of preparing a specific molecular state easier or harder?

CHRISTIANE: We are looking into this at the moment, not for the case of a magnetic field but a static electric field. My gut feeling is that it will make things easier but we do not yet have a rigorous answer.

Is there an interest in merging optimal control techniques with other techniques like machine learning tools?

CHRISTIANE: It's really two sides of the same coin. In particular, machine learning and parameter optimization seem to be fairly closely related and should perform similarly numerically and in terms of scaling. We hope to look into this more closely in the future.

What is the limitation on the size of molecules to which these techniques could be applied? Is there any chance of applying this to larger biological molecules, for example?

CHRISTIANE: There is no strict limitation because all that we are using is the property of the molecules being (rigid) asymmetric top rotors. For very, very large molecules, the rotational spacings might become too small to selectively address transitions though.

Maciej Lewenstein: There is a new area of looking at chirality with strong laser fields: Olga Smirnova, Misha Ivanov and more. Probably also asking for quantum control for design of laser pulses, polarizations, OAMs

CHRISTIANE: Of course! There are many more aspects to this and it is a really exciting field but I decided to focus today on microwave three-wave mixing.

Yaakov Yudkin: The fact that you first create a spin coherent state and then rotate it, is that put in by hand because you knew in advance that it would work or is that the outcome of the optimization which you understand in hindsight?

CHRISTIANE: It was the outcome of the optimization but once we understood what the dynamics driven by the optimized field is, we used the insight to simplify the pulse, e.g. flatten the pulse amplitude for the rotation.

As an experimentalist, have these methods been adapted to work in the presence of experimental noise? For example, let's say that I understand the spectral properties of the noise affecting my qubits very well, can this be taken into account? If so, what are the limitations?

CHRISTIANE: Yes, they have been adapted, and yes, if I know the noise properties, I can look for controls that work despite the presence of noise. There are some examples in the literature for toy models that demonstrate this but nothing so far with realistic noise models, as much as I am aware of. I would definitely like to try if an experimentalist would tell me their noise properties! Even though there is no guarantee that you will find a good control – whether there is a chance for that or not would be answered by a controllability analysis but for systems with non-Markovian dynamics almost nothing is known about their controllability. It's a wide open field so discoveries can be made.