Everything You Always Wanted to Know About Atom Tunneling & Photon Propagation but Were Afraid to Ask

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If there are two problems you would think quantum mechanicists & opticians had beaten to death, they might be quantum tunneling and the propagation of photons through a cloud of atoms.

And yet when you look more deeply -– and ask ”where are the atoms while they're tunneling through the forbidden region, and how much time do they spend there?” or ”how do photons get slowed down, and where is the energy spending its time?” – the answers are not so simple.

This is related to a simple reality: one of the most famous tidbits of received wisdom about quantum mechanics is that one ”cannot ask” how a particle got to where it was finally observed, *e.g.*, which path of an interferometer a photon took before it reached the screen. What, then, do present observations tell us about the state of the world in the past? I will describe two experiments looking into aspects of this ”quantum retrodiction”. In the first, we measure how long Bose-condensed atoms spend inside a potential barrier (created by a far-detuned laser beam focused to 1 micron) before being transmitted; I will also talk about some predictions regarding what insidious effects actually observing a particle in the barrier could have. In the second, we measure the amount of time atoms spend in the excited state when a resonant photon is not absorbed by those atoms, but propagates clear through. We find, surprisingly, that the answer need not even be a positive number. I will connect this to better-known aspects of optical propagation.

I will also describe the observation of (initially) surprising "spin textures" in the tunneling cloud that illuminate novel features of cold-atom magnetohydrodynamics; and planned experiments to study the timescales relevant to quantum measurement in a tunneling scenario.

References

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