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Two-photon Rabi oscillations in hydrogen: A theoretical study of effective Hamiltonian approaches

Popular Science Abstract

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All matter in our world is made up of atoms. What determines the properties of matter is the behaviour of the electrons in the atoms. This behaviour can be studied and controlled by exposing the electrons to light.

An electron bound in an atom can only take on discrete energy values, so-called energy states. By shining light on the electron, we may induce it to jump to a higher energy state; we call this a *one-photon transition*. How far the electron jumps is determined by the colour of the light. Fascinatingly, if the colour perfectly corresponds to the energy between two energy states, we may observe the electron periodically jumping up and down between two energy states. This is known as *Rabi oscillations*. What is especially interesting is that the electron goes from being fully in the lower energy state, to being in both states at once, and then to fully inhabiting the upper energy state, before returning down again to repeat the cycle. That the electron at one time is fully in the upper state is not self-evident because the quantum world is based on probabilities.

Under special conditions, the electron may not take one single jump to reach an upper state, but may jump twice at once – a so-called *two-photon transition*. In atoms, energy states that can be reached by one jump cannot be reached by two simultaneous jumps, and vice-versa. This makes two-photon transitions very relevant: We can try to use them to get the electron to energy states which can under normal circumstances not be reached. If the colour and intensity of the light is just right, we may observe two-photon Rabi oscillations of the electron, where the electron at one point fully inhabits the upper energy state.

Describing two-photon Rabi oscillations can be challenging since, inbetween the electron's two jumps, it lands in a third so-called *virtual energy state*, which we may envision as an invisible trampoline. The probability to find the electron in the virtual state is 0%. As such, we are not interested in these virtual states; our only interest concerns the two energy states between which the electron oscillates. Through an approximation known as *adiabatic elimination*, we can remove any virtual states from the mathematical description and create the *effective Hamiltonian*, a mathematical object which describes what happens to the two important energy states.

In my thesis, I focus on two aspects: Firstly, I propose a systematic way to improve upon adiabatic elimination. Secondly, I investigate two-photon Rabi oscillations in hydrogen. For previously considered energy states, these were found to be impossible. However, by investigating previously unconsidered higher energy states, I predict that two-photon Rabi oscillations can be observed in hydrogen if the colour and intensity of the light is chosen carefully. Perhaps, these can in the future be found experimentally. With ever stronger lasers, the theoretical framework I propose for the description of two-photon Rabi oscillations may find use in the description of other strong-field light-matter processes.

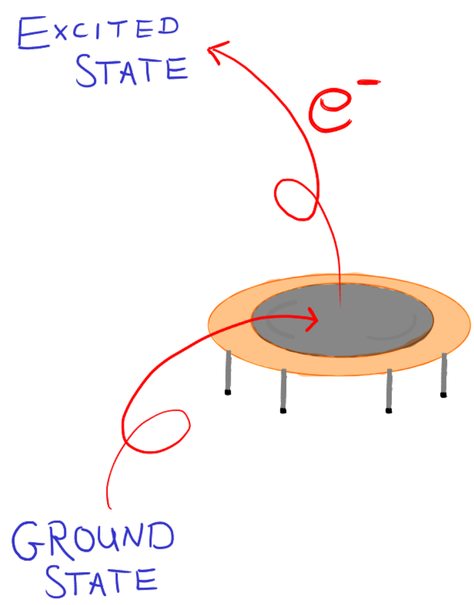

Fig. 1: Illustration of an electron $\mathbf{e}^-$ jumping between two energy states.