Non-resonant transitions: Insights from quantum-thermodynamics

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Discrete energy levels in atoms and optical transitions with photon energies matching their energy differences are the hallmark of quantum theory. However, due to the uncertainty relation, the photon energy can differ from this transition energy if the excited atom has a finite lifetime. Such non-resonant transitions can be enforced by using an optical cavity with a frequency higher than the transition frequency. In this process, energy conservation seems not to be fulfilled, which motivates the detailed thermodynamic study presented here [1]. It is demonstrated that the associated filling and emptying of the levels from/to reservoirs occurs at average energies differing from the bare level energies. Using these new effective energies, the entire process is shown to be consistent with the first and second law of thermodynamics. This allows for a detailed understanding of a variety of physical processes such as frequency pulling in a laser or Bloch gain for intersubband transitions in semiconductor hetero-structures.

[1] A. Wacker, Phys. Rev. A 105 (2022), 012214.