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Implementing quantum algorithms in hyperfine levels of ultracold polar molecules

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Synopsis Using optimal control, we implement simple quantum algorithms using hyperfine states of ultracold polar molecules. The qubits are encoded in hyperfine states of isolated $^{41}K^{85}Rb$ or $^{41}K^{87}Rb$ molecules or in hyperfine states of two neighboring molecules.

To simulate a molecular quantum computer, two problems must first be overcome : the implementation of multi-qubit gates acting on the states of a single molecule (*intra*molecular gates) as well as gates acting on qubits encoded on the states of neighboring molecules (*inter*molecular gates). The latter are necessary to ensure scalability, as the number of individually addressable qubits in a single molecule cannot be increased indefinitely.

The long-range anisotropic dipole-dipole interaction of polar molecules is a potential solution to scalability [1]. Moreover, the recent exhaustive study of the microwave spectra of ultracold alkali metal dimers in magnetic and/or electric fields has raised the matter of the influence of hyperfine states on quantum information manipulation [3]. It was shown that their rich structure in a magnetic field could be favorable for encoding qubits with very long life time and allow unitary transformations via intermediary states [2].

Using optimal control, we implement multi-qubit quantum gates on the hyperfine states of the $^{41}K^{85}Rb$ molecule and its isotopologue $^{41}K^{87}Rb$ using optimal control. The following algorithms are carried out :

1. A three-qubit adder of 0 and an adder of 1 on hyperfine states of $^{41}K^{85}Rb$.
2. A three-qubit Grover search algorithm on hyperfine states of $^{41}K^{85}Rb$.
3. A two-qubit Grover search algorithm using hyperfine states of two neighboring $^{41}K^{87}Rb$ molecules.

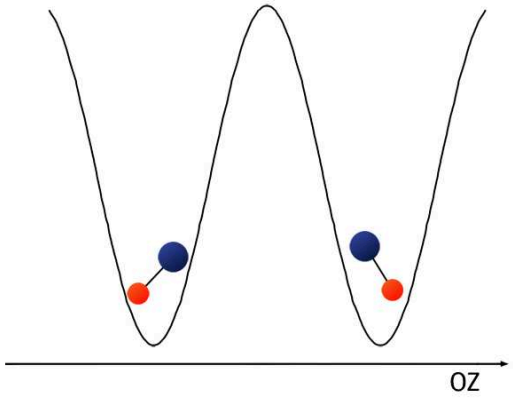

Figure 1. The neighboring $^{41}K^{87}Rb$ molecules are modeled as trapped in an optical lattice and exposed to an electric field with a gradient along OZ to differentiate their respective hyperfine states

The laser pulses may be realizable experimentally thanks to their relative simplicity and their suitable wavelength range.

References

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