Towards light-activated entangling gates based on molecular spin qubits

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Abstract: The light-activated interaction between porphyrin-based spin qubits represents a first step toward the realization of individually addressable qubits with switchable interactions - an essential prerequisite for scalable quantum architectures.

Molecules provide a modular and chemically tunable platform for quantum information science. In recent years, significant advances have been made in enabling optical spin initialization, coherent control, and both optical and electrical readout of molecular qubits.[1] Yet, a central challenge remains: realizing scalable architectures through the controlled and ultrafast activation of inter-qubit interactions. Here, we present a molecular system composed of two vanadyl porphyrin qubits bridged by a free base porphyrin chromophore, where the qubits are magnetically independent in the ground state but become coupled upon photoexcitation.[2] Femtosecond transient absorption and time-resolved electron paramagnetic resonance experiments, supported by DFT calculations and spectral simulations, reveal that photoexcitation induces the formation of a spin-quintet state within sub-picosecond timescales. Notably, long-lived spin polarization persists up to room temperature. Theoretical modeling offers design principles for harnessing this mechanism in future applications, such as the operation of a light-controlled $\sqrt{iSWAP}$ entangling gate. These results provide a proof of concept for optically controlled spin interactions in molecules, paving the way for light-activated molecular quantum gates.

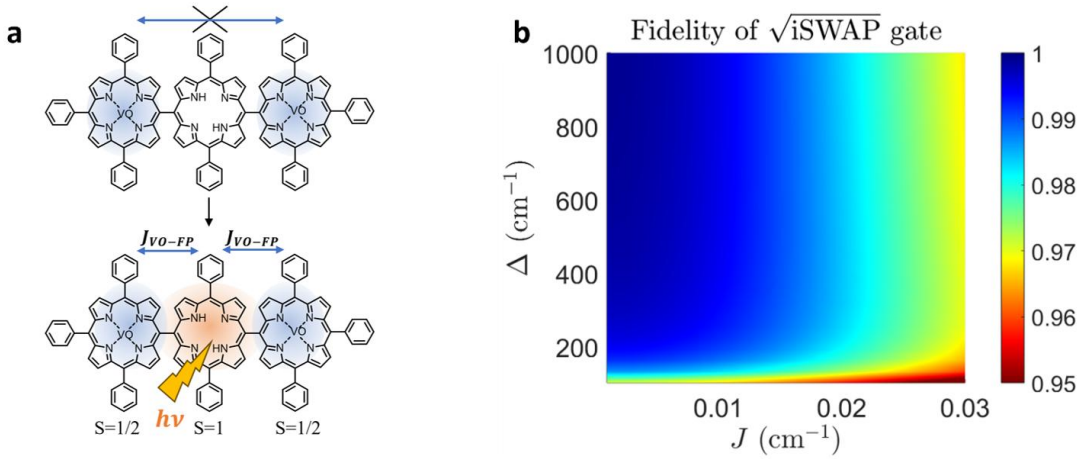

Fig. 1. a) Mechanism of light activation of the interaction between vanadyl qubits through a bridge photo-excited in the triplet state; b) Computed fidelity of the $\sqrt{iSWAP}$ light-controlled gate.

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[2] A. Privitera, A. Chiesa, F. Santanni, D. Ranieri, P. P. Sahu, M. D. Krzyaniak, A. Caneschi, R. M. Young, M. O. Senge, F. Totti, M. R. Wasielewski, S. Carretta, R. Sessoli,A. Privitera et al., Light-Activated Qubit Coupling in a Vanadyl Porphyrin Trimer. J. Am. Chem. Soc. (2026). available online https://doi.org/10.1021/jacs.5c17205