Investigating the Quantum Mechanism for Magnetorecption in Birds

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Objectives

- Understand the role of quantum coherence and entanglement in the biological compass system.
- Explore the potential role of a quantum phase transition in the local nuclear environment.

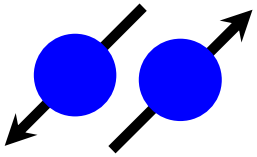
Induction Loops

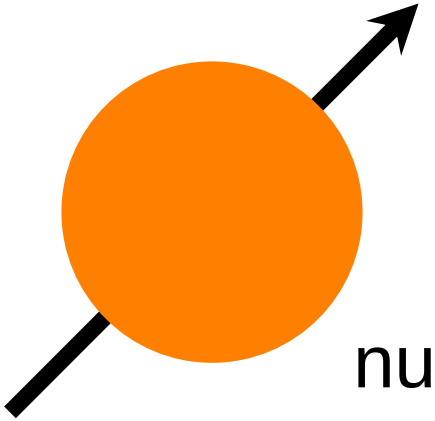
Magnetite Receptors

Radical Pair Mechanism

The RPM model:

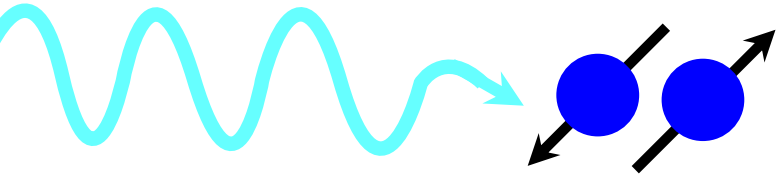
antiparallel electron pair

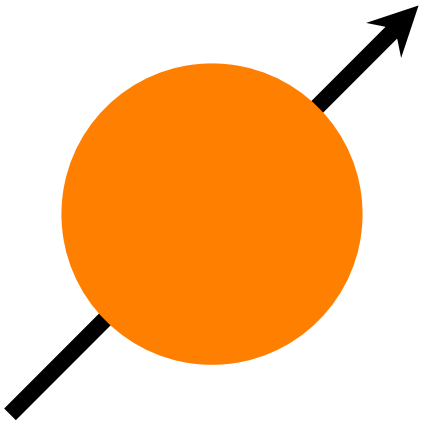


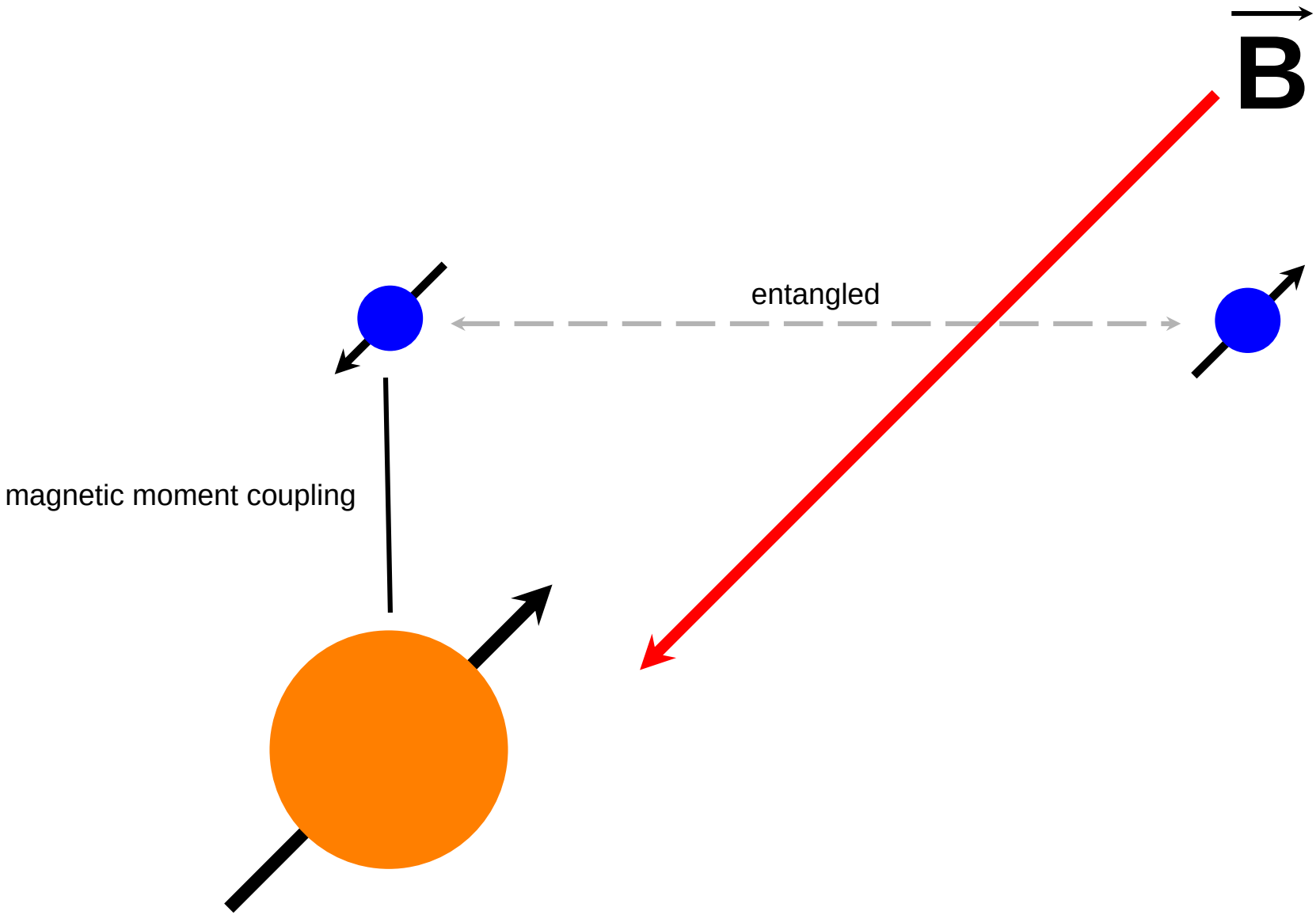


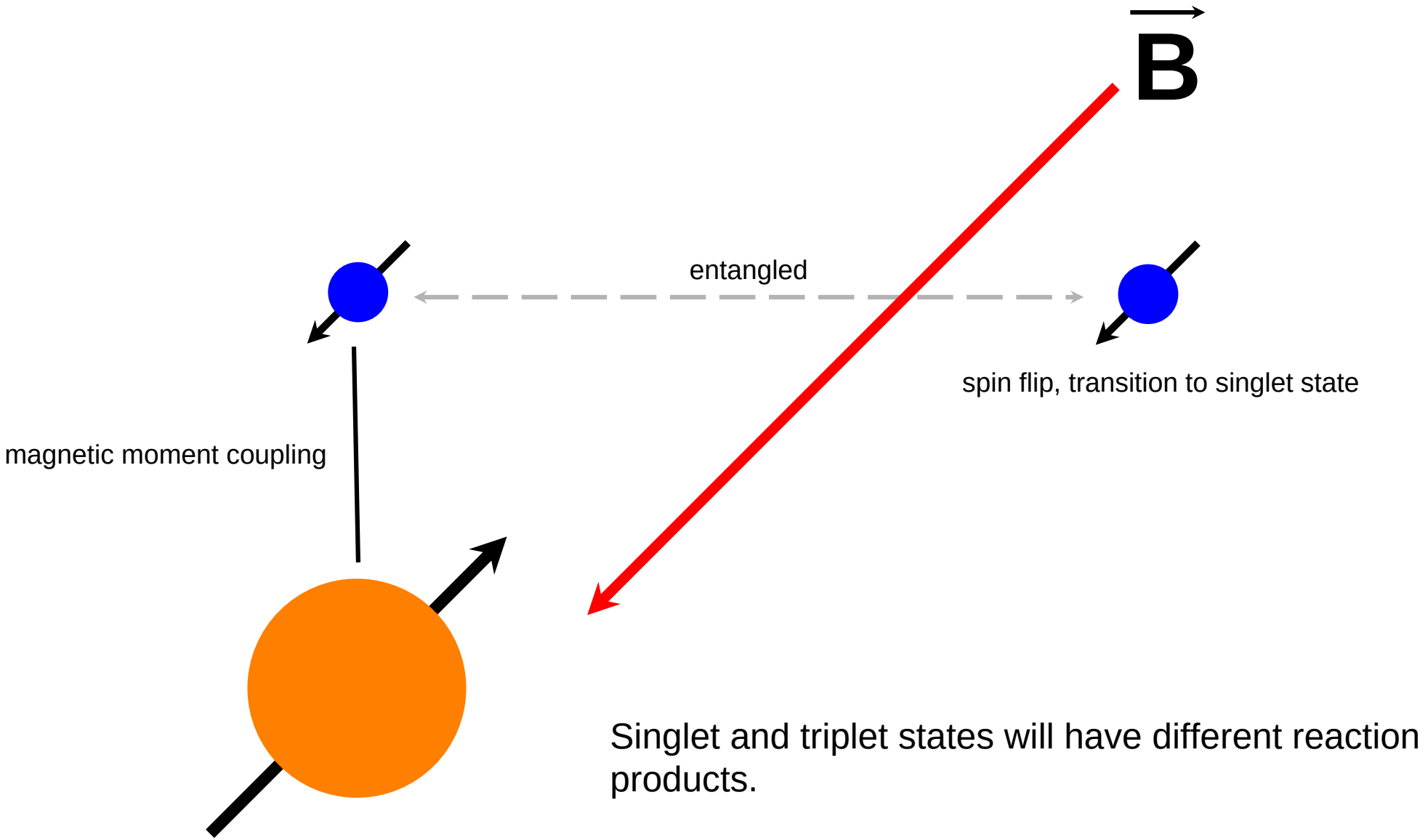
nuclear spin

blue photon



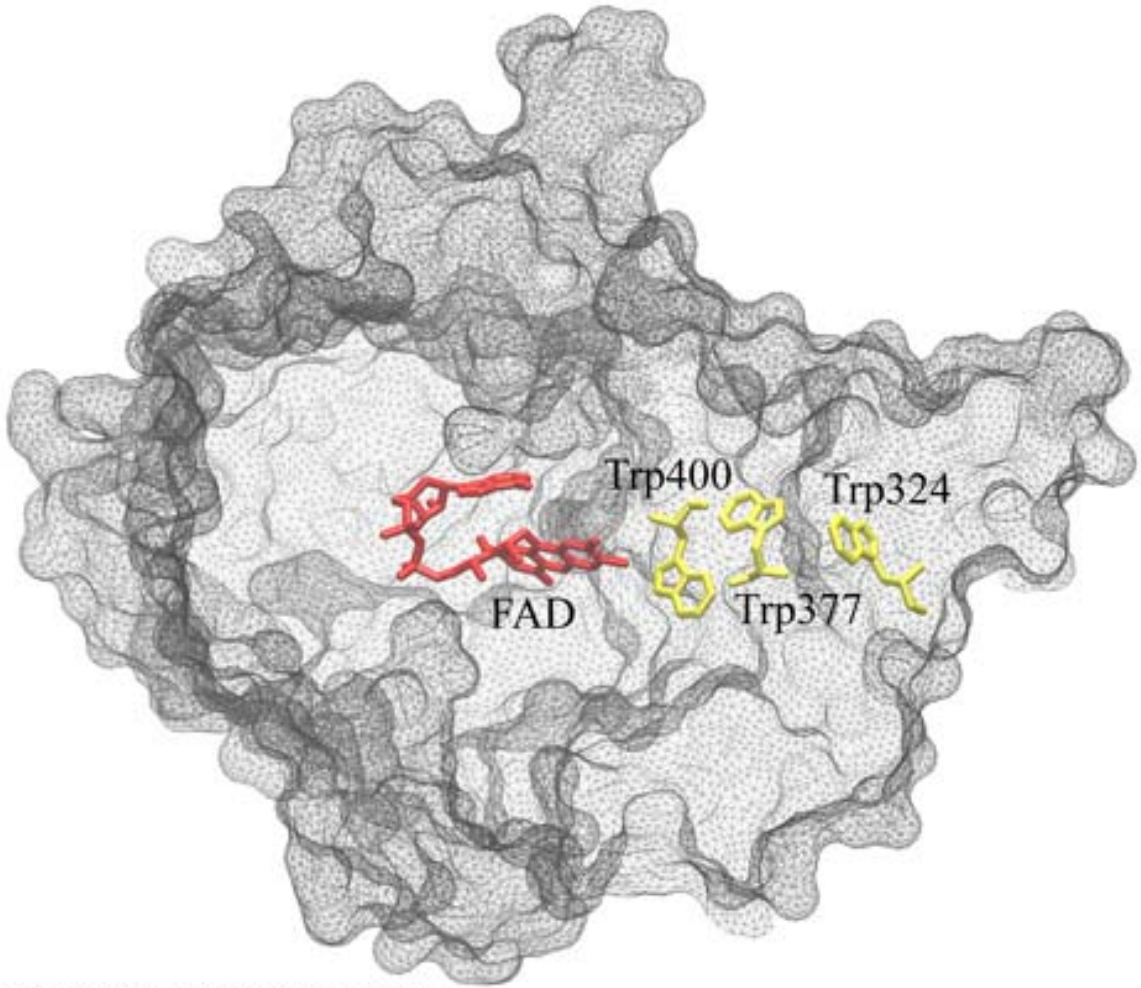



$\vec{B}$
entangled
magnetic moment coupling



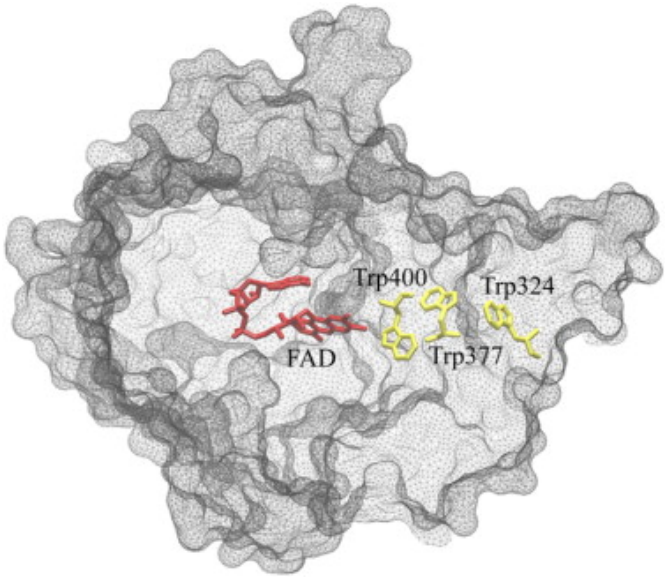
Singlet and triplet states will have different reaction products.

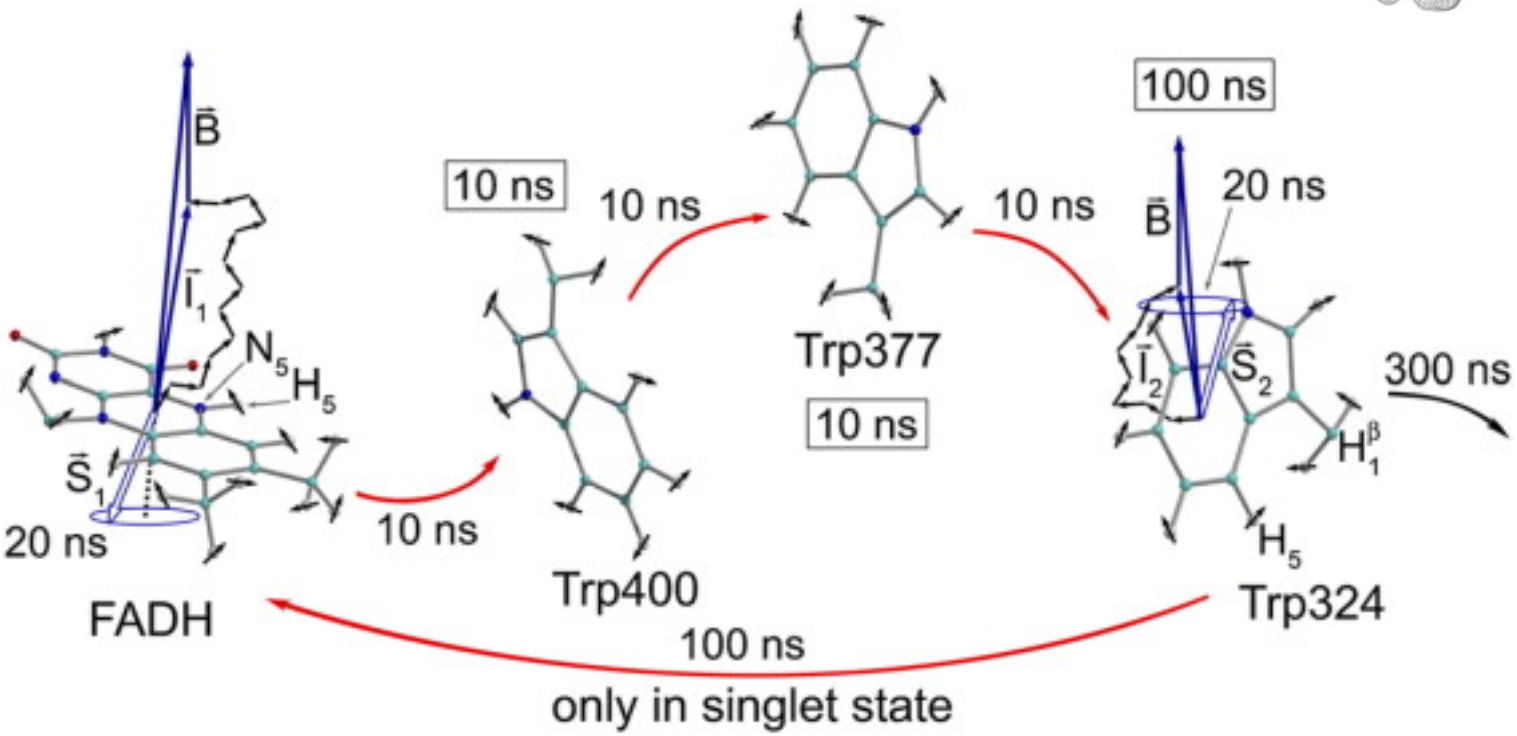
Cryptochrome Molecule



Theoretical and Computational Biophysics Group
Beckman Institute
University of Illinois at Urbana-Champaign

Excitation and Electron Hole Transfer



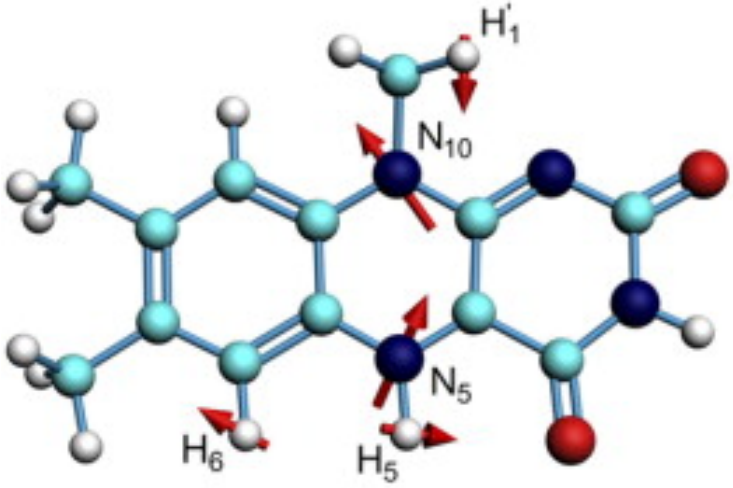


6.0 Angstroms ⟷

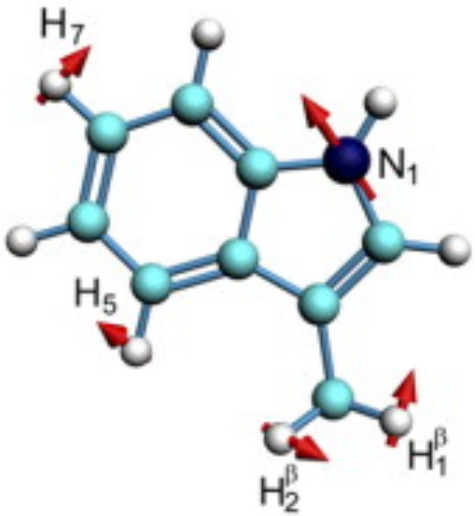
8.9 Angstroms ⟷

13.3 Angstroms ⟷

Structure and Energy Levels

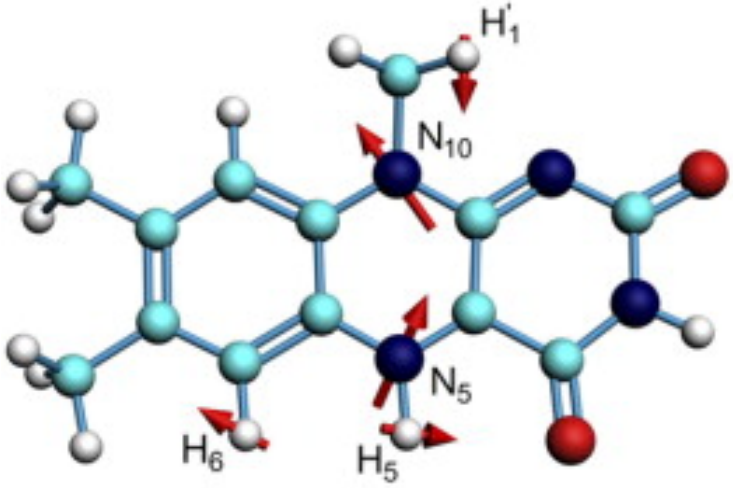


FADH

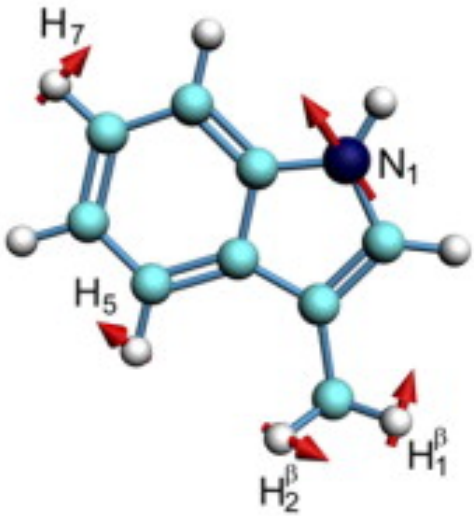


Tryptophan

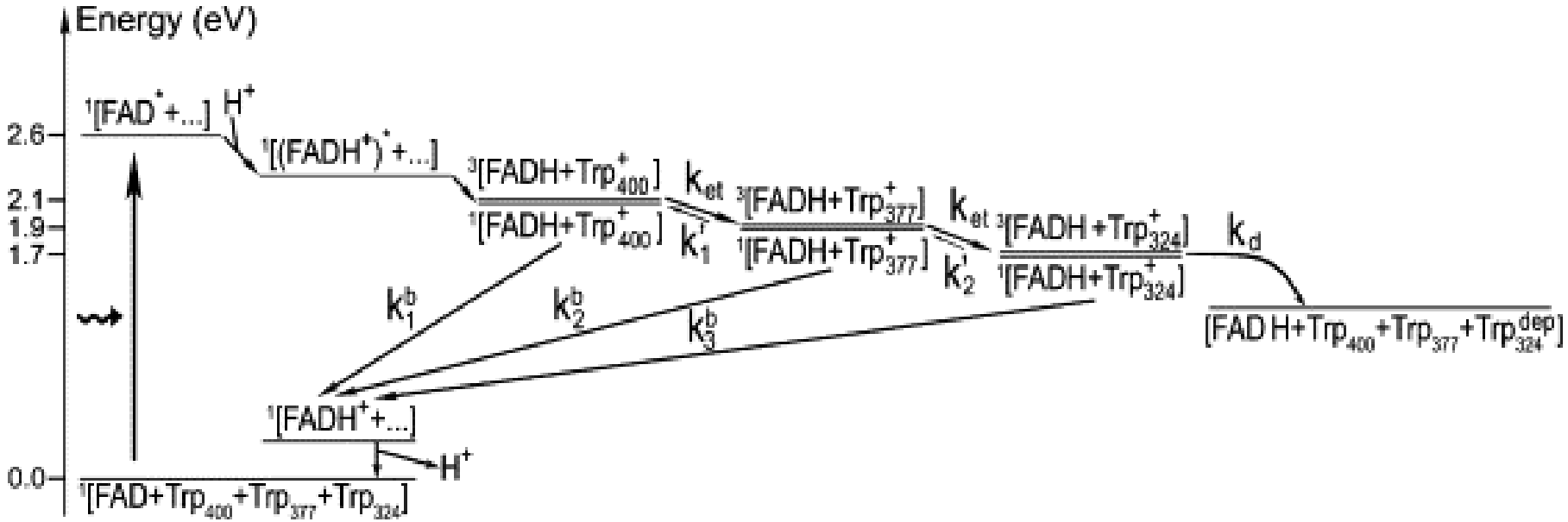
Structure and Energy Levels



FADH



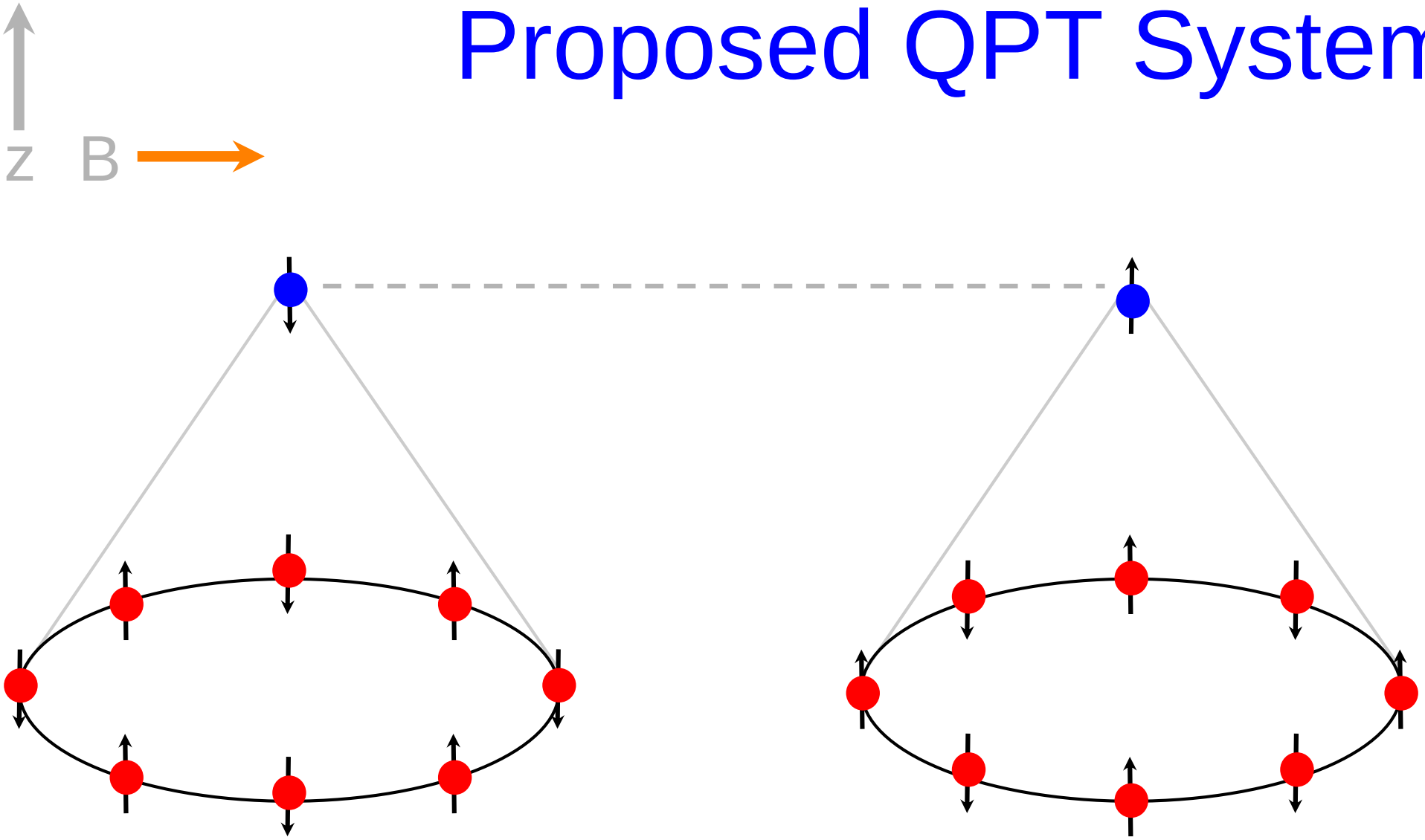
Tryptophan

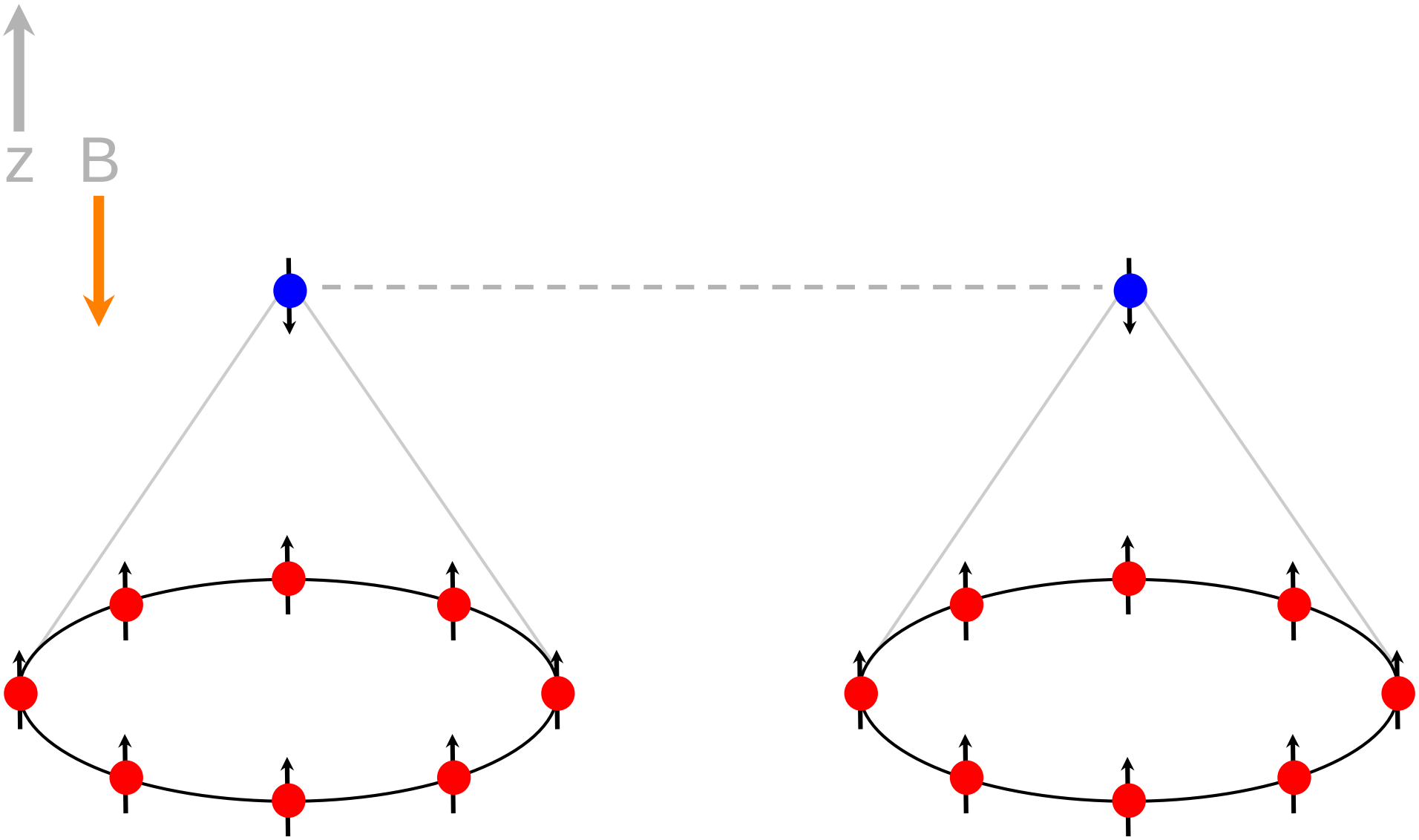


Rationale for a Radical Pair Mechanism

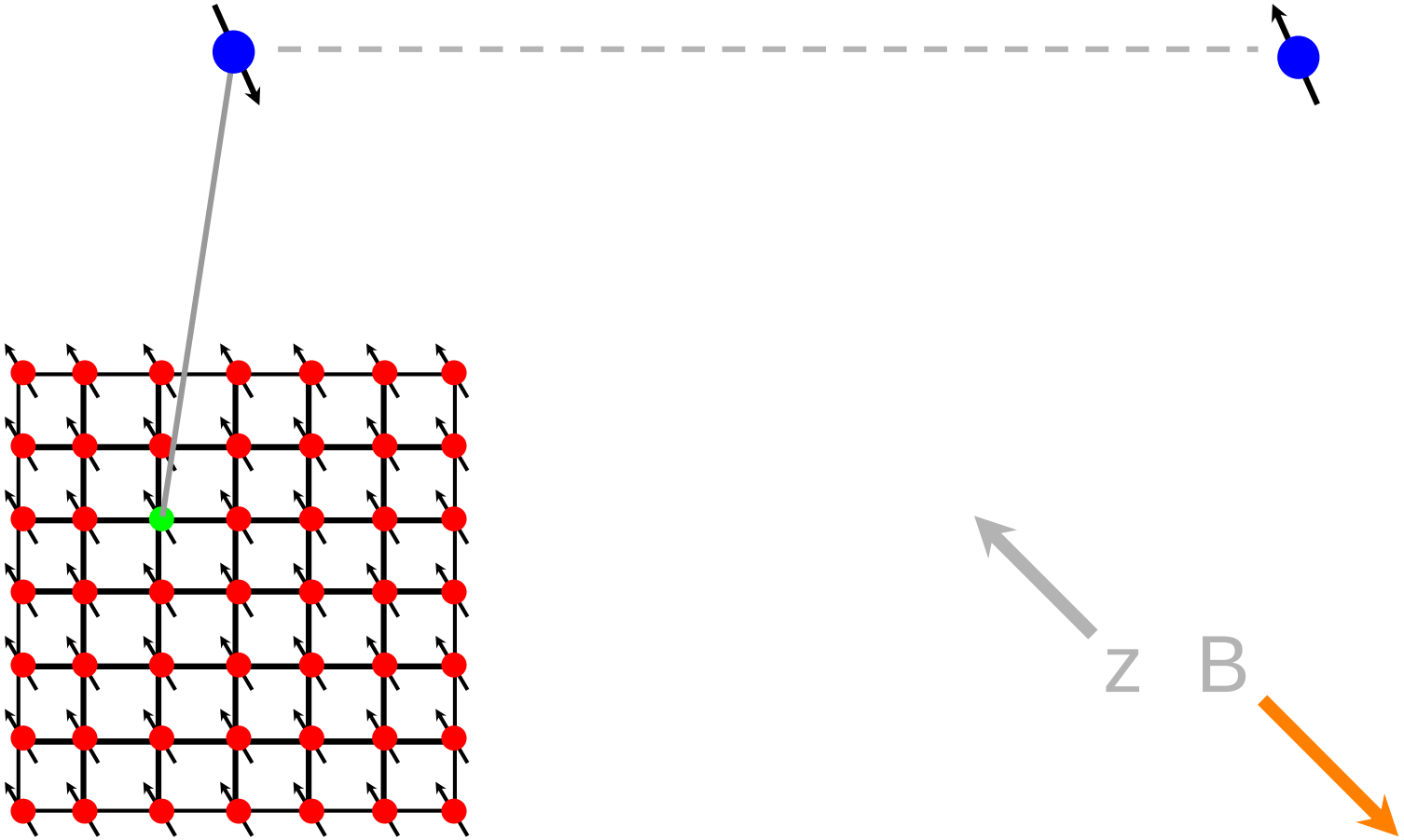
- Orientation of birds is effected by certain wavelengths and intensities of light.
- Radio frequency interference.
- Cryptochrome is found in many birds' retinas.
- Demonstrated role in magnetic orientation of fruit flies.

Proposed QPT System




z
B

A Revised QPT Dependent Model



My Proposed Hamiltonian

$$H = I^{z} \cdot A \cdot R(\theta, B) \cdot \sigma_{1}^{z} + \gamma \cdot B \cdot \left(\sigma_{1}^{z} + \sigma_{2}^{z} \right)$$

Conditions and Assumptions for Simulation and Calculations

- 2-D ising lattice, closed boundary conditions.
- 100 and 400 spin sites.
- Hydrogen/Proton for spin sites.
- aprox. 800 picometers between sites.
- 300 K.
- B = 4.7 T for GMT.

Revised Environment

- 2-D ising lattice, closed boundary conditions.
- 100 and 400 spin sites.
- Nitrogen nuclei.
- aprox. 8 nanometers between sites.
- 0 K.
- B = 4.7 T for GMT.

Results and Conclusion

- A QPT in the magnetic property of the spin environment does not occur under realistic environmental conditions.
- RPM system is likely a relatively small group of objects, limited to the local environment.

Continuing Research Goals

- Investigate entanglement in the system in the presence of quantum noise and disorder.
- Model and characterize the environmental electronic structure: singlet-triplet splitting, ring currents, etc.
- Spin correlation and its effects on the chemistry of the system.

Acknowledgements

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