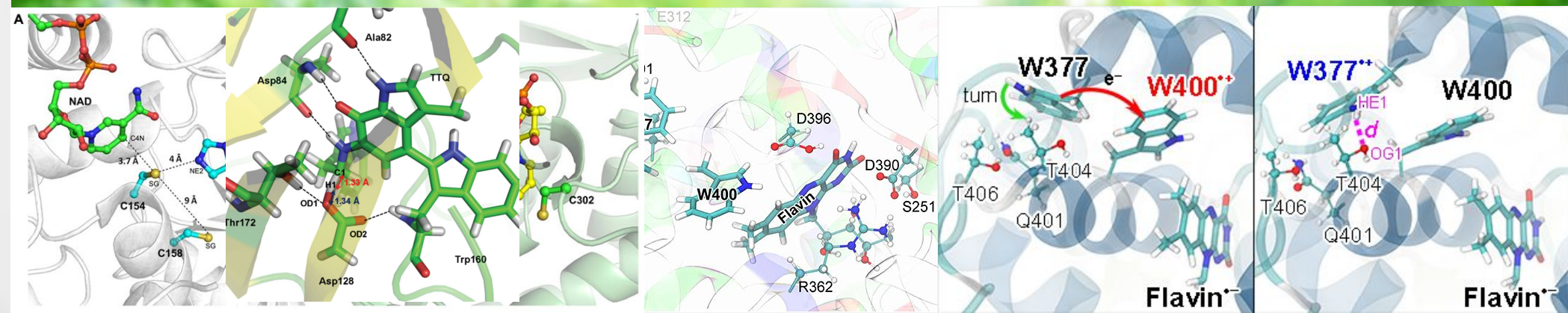


A REVIEW OF STUDIES ON QUANTUM BIOLOGY

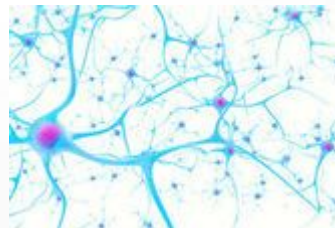
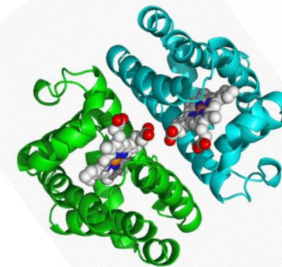


Outline of talk

Basic points of Quantum theory

Examples of processes which biological effect is impossible to explain without the involvement of quantum mechanics and they are not determined by the properties of individual atoms:

- Primary processes in photosynthesis
- Enzyme-catalysed reactions
- Avian magnetoreception
- Brain's function



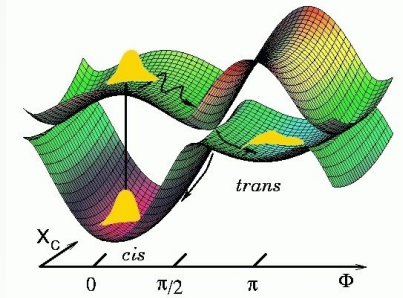
Three classes of QM influence in biology

1. **The trivial:** QM dictates energies, molecular orbitals, etc.

2. **Molecular dynamics and chemical kinetics:**

e.g.

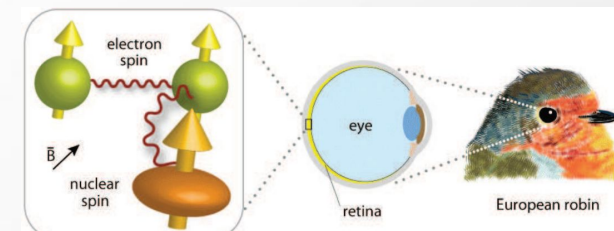
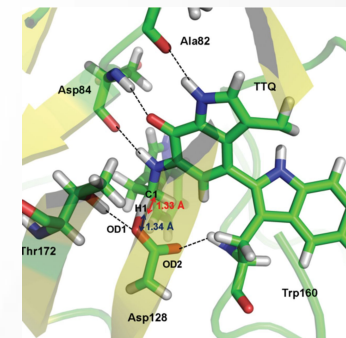
- Ultra-fast molecular transitions through conical intersections
- **Chemical reactions involving electron & proton Tunneling**



3. **Functional necessity:**

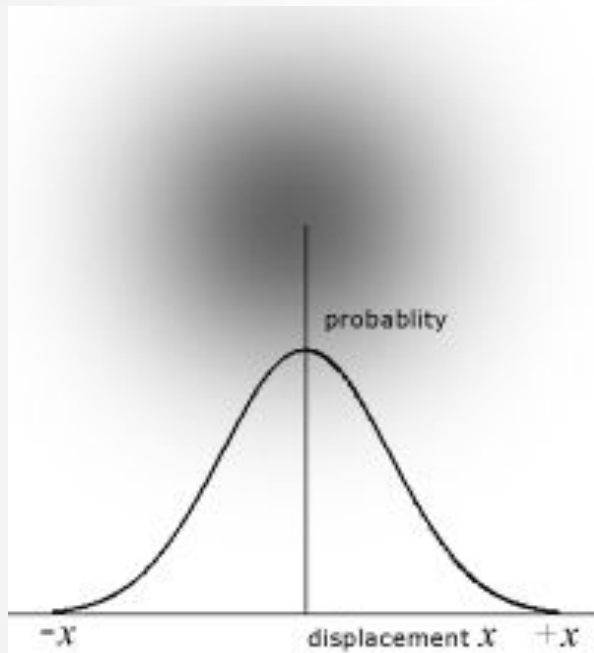
e.g.

- **Magnetoreception in birds**
- Olfaction (vibration assisted electron tunneling)
- **Photosynthetic light harvesting**
- **Brain's function**



Quantum theory: basic points

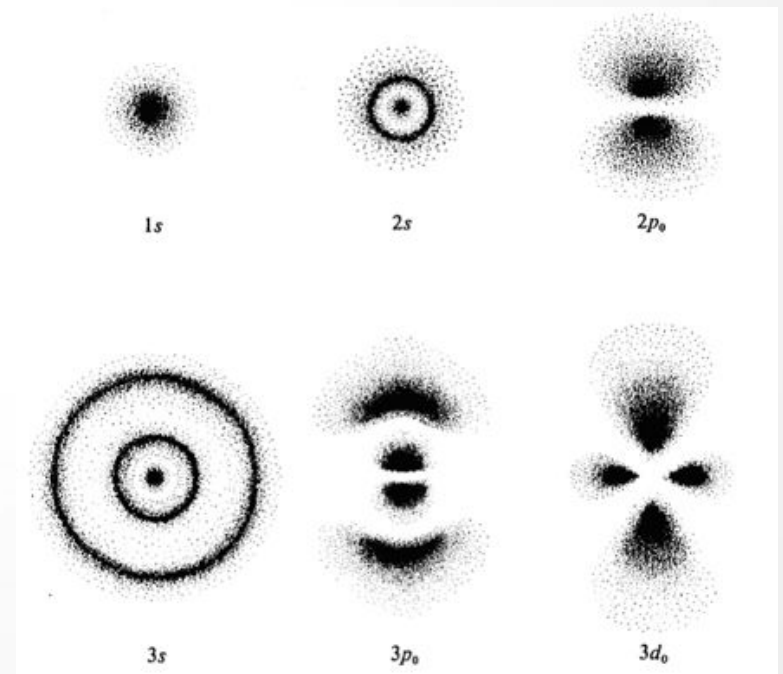
- The wave properties of particles relates to their statistical position about a point

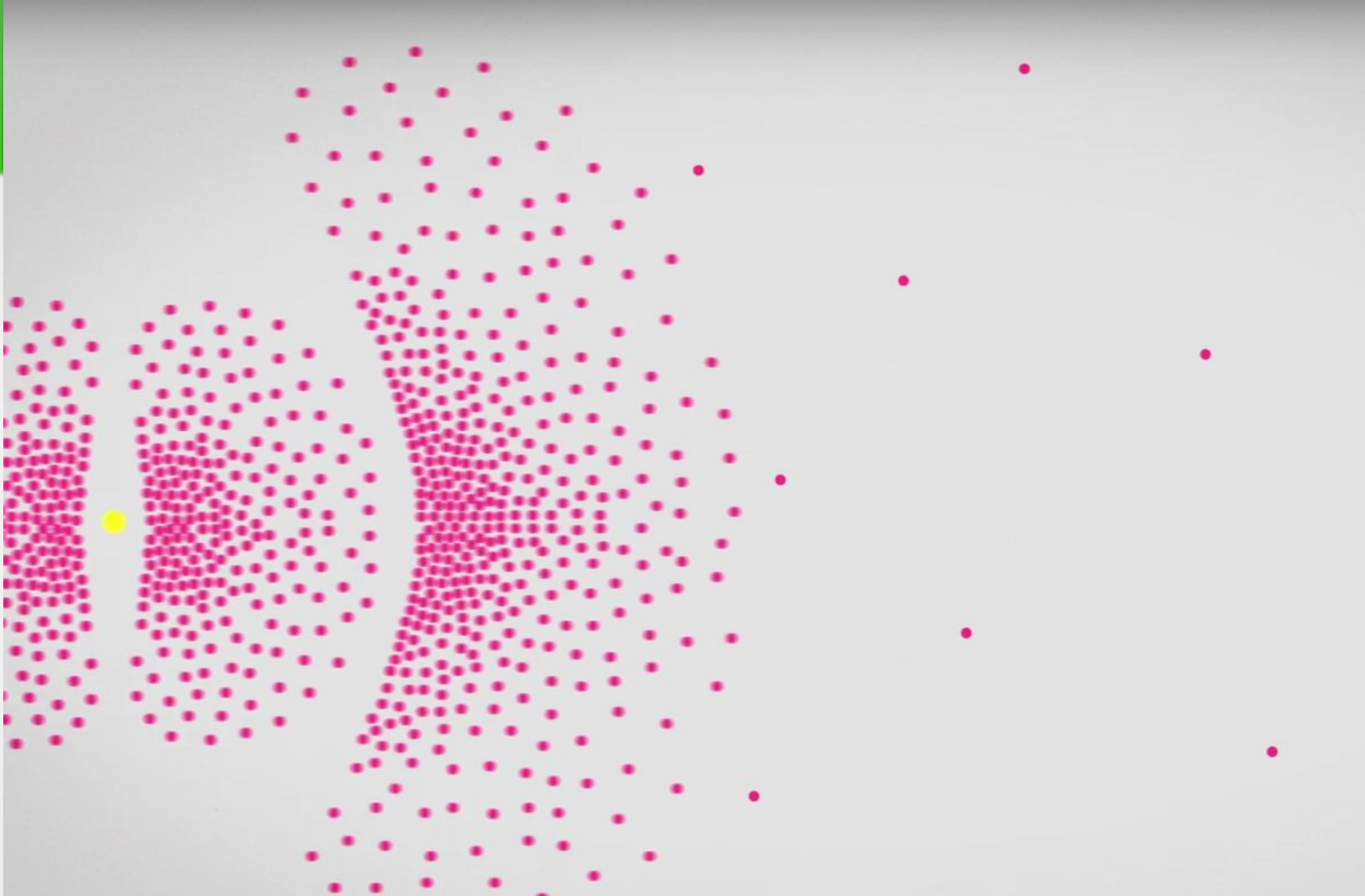


- The wave nature of matter is described in some detail by the Schrödinger Wave Equation.

The wave function is used to give information on:

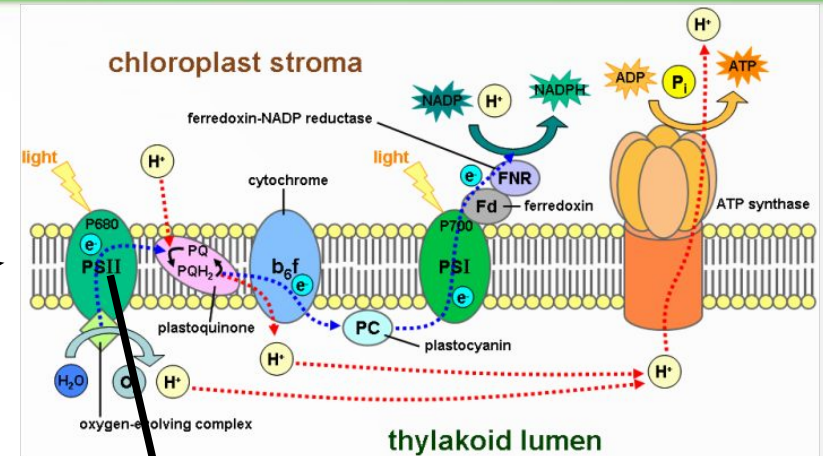
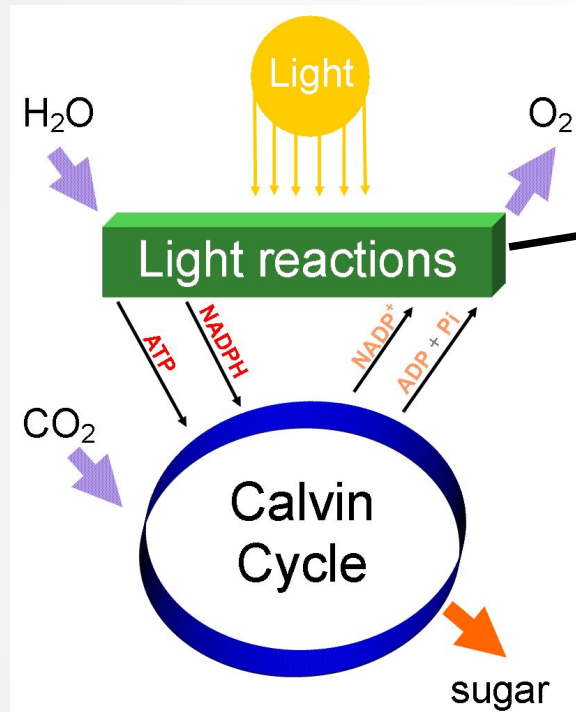
- probability distributions in 1D, 2D or 3D
- quantum states
- energy levels





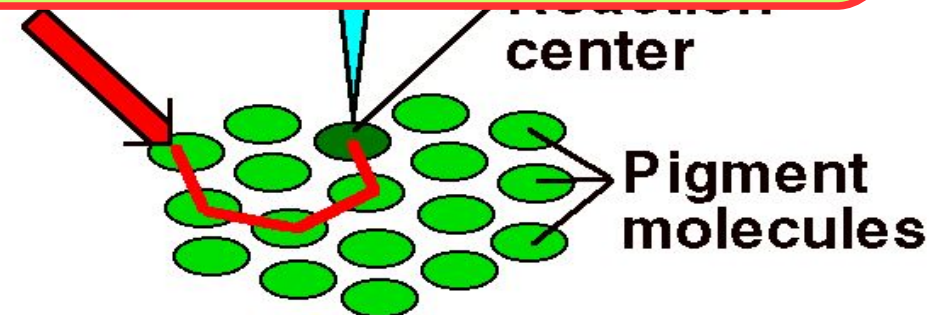


Photosynthesis

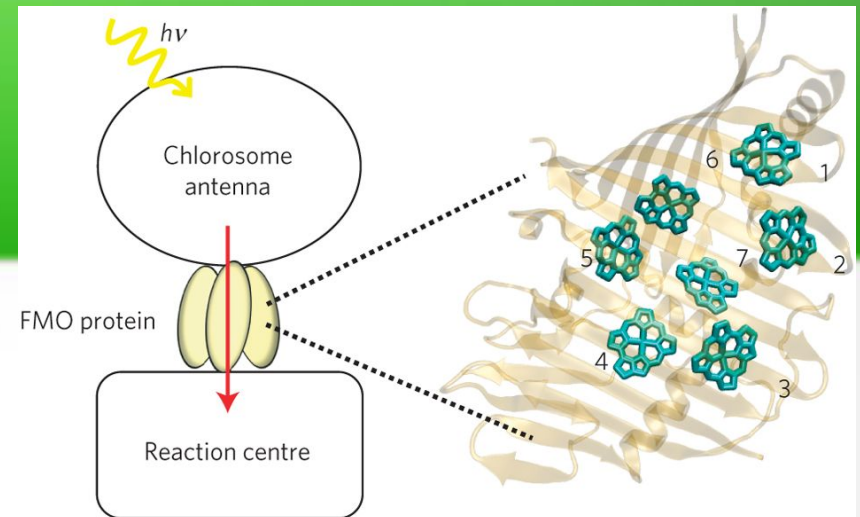


Primary acceptor

The efficiency of this process is close to 100%



Quantum coherence in light harvesting: experiments



FMO: energy „wire“ connecting chlorosome to reaction center

Green sulfur bacteria

Fenna-Matthews-Olson (FMO) complex:

Engel et al., Nature, 446, 782 (2007) (T=77K)

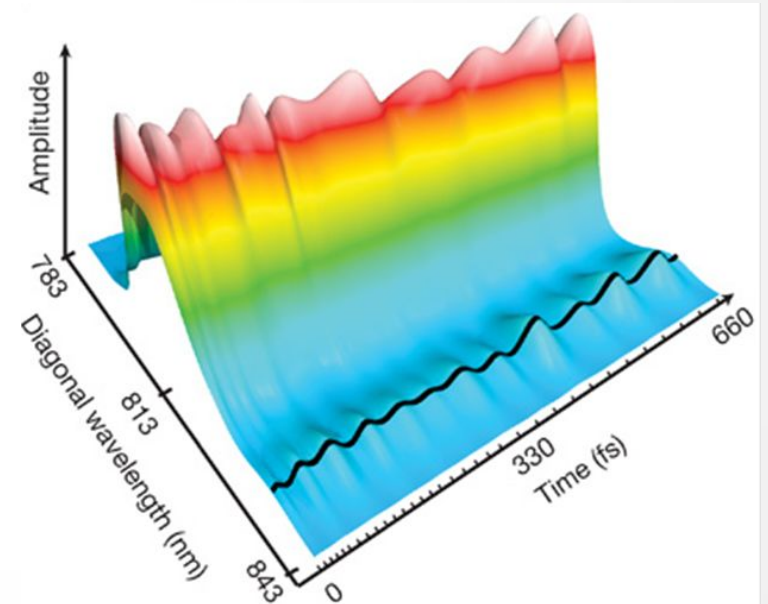
Panitchayangkoon et al., PNAS 107, (2010) (T=277 K)

Mostame et al., New Journal of Physics 14:105013 (2012)
(Quantum Simulator of the system)

Abramavicius, EDP Sciences (2013)
(simulating using the stochastic Schrodinger equation)

Aref'eva, Volovich; JHEP (2016)
(the holographic approach to photosynthesis)

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K

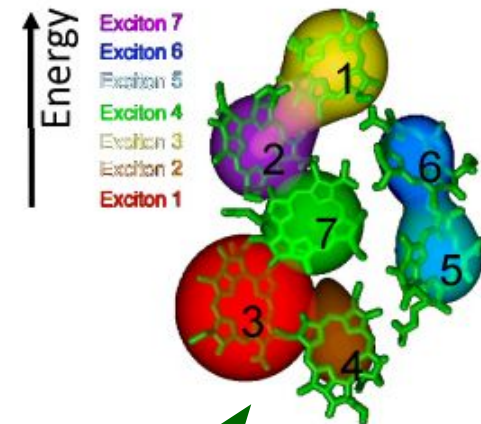
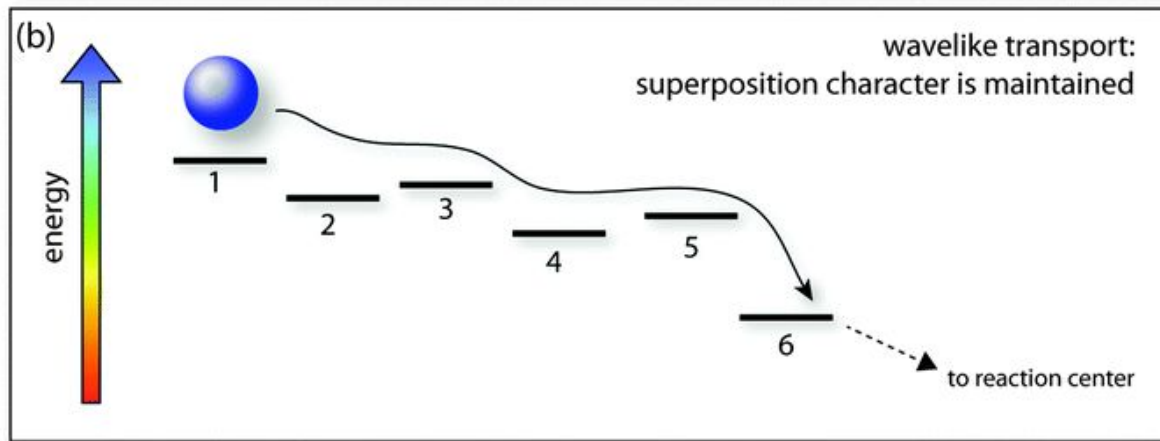
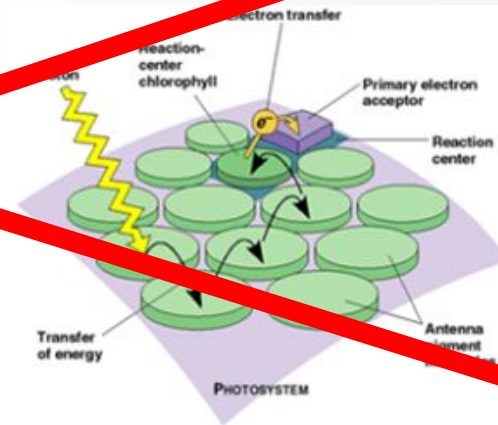
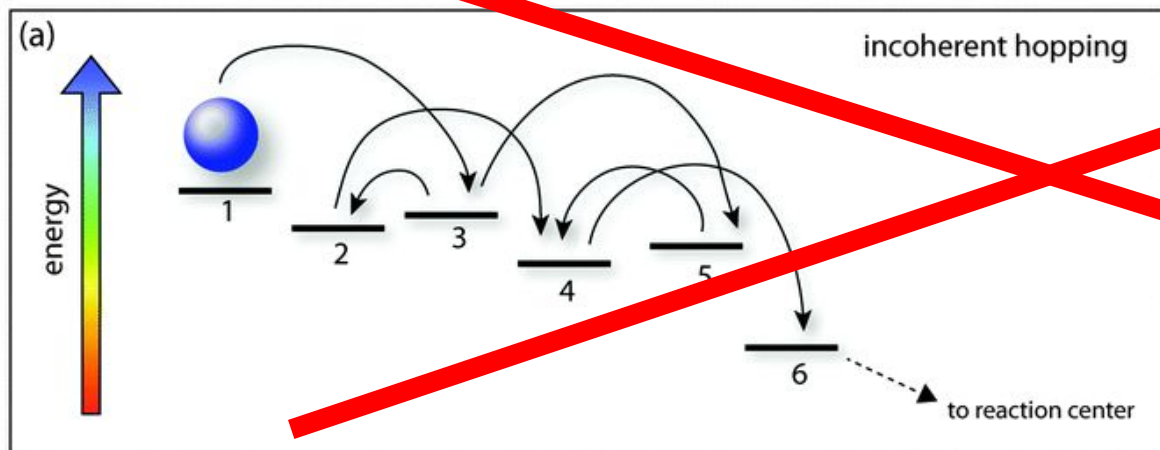
$\tau=6$

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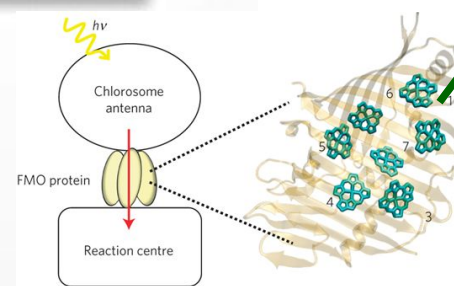
Evidence for wavelike energy transfer through quantum coherence in photosynthetic systems", G.S. Engel, et al., Nature 446, 782 (2007)

Quantum coherence in light harvesting

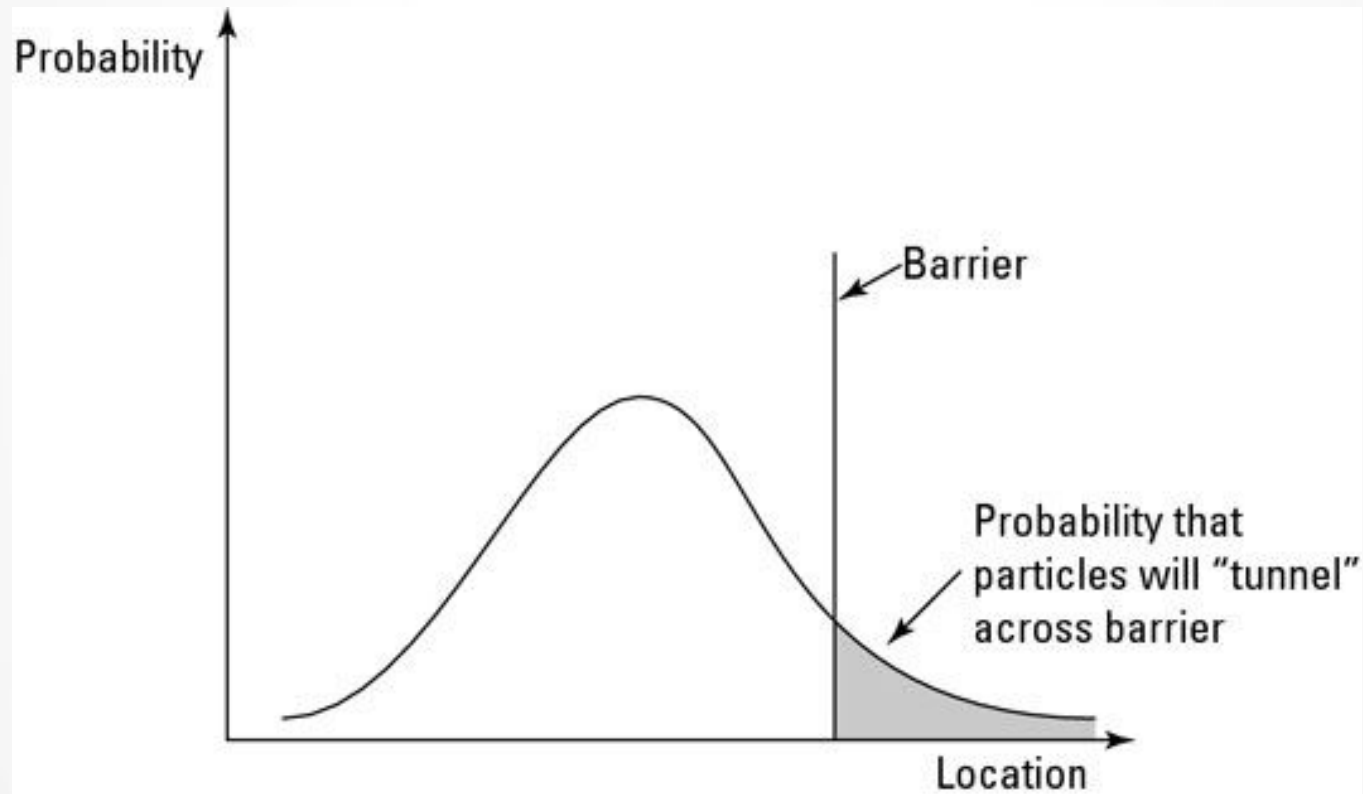


E. Collini Spectroscopic signatures of quantum-coherent energy transfer *Chem. Soc. Rev.*, 2013,42, 4932-4947

M. Sarovar The meeting of quantum physics and biology /American Physical Society March Meeting, Baltimore, 2013



Quantum tunneling



Quantum Tunnelling in Enzyme-catalysed Reactions



Rudolf K. Allemann



Nigel Scrutton



Judith P. Klinman



Zachary Nagel



Chem. Rev. **2006**, *106*, 3095–3118

3095

Tunneling and Dynamics in Enzymatic Hydride Transfer

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Department of Chemistry and Department of Molecular and Cell Biology, University of California, Berkeley, California 94720

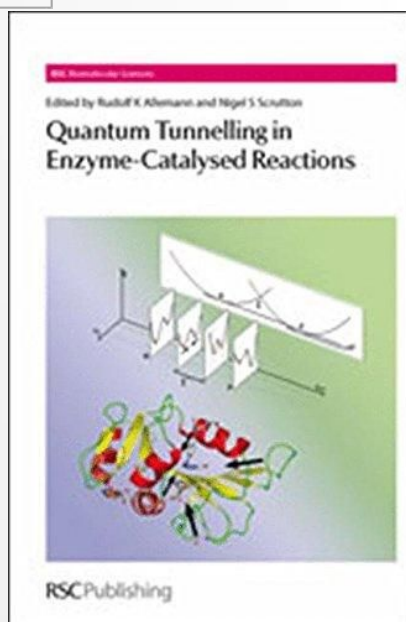
Received January 23, 2006

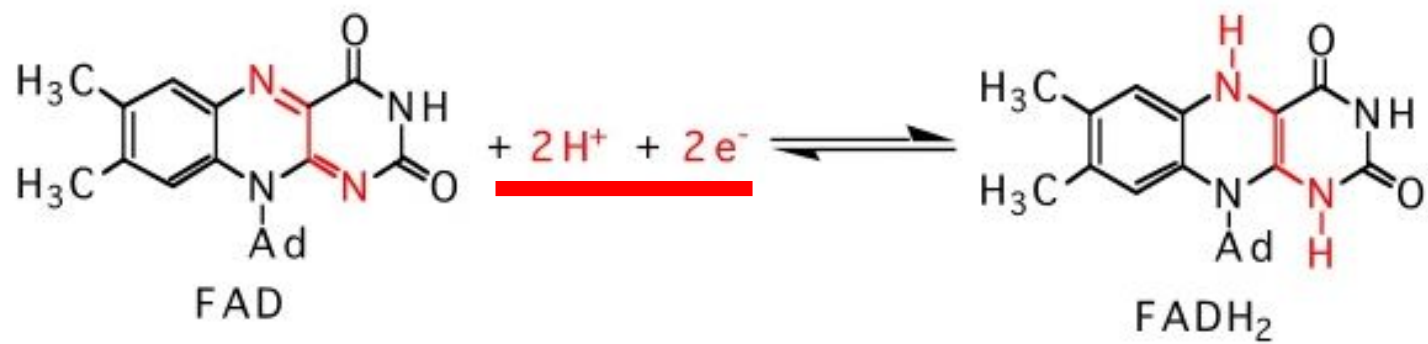
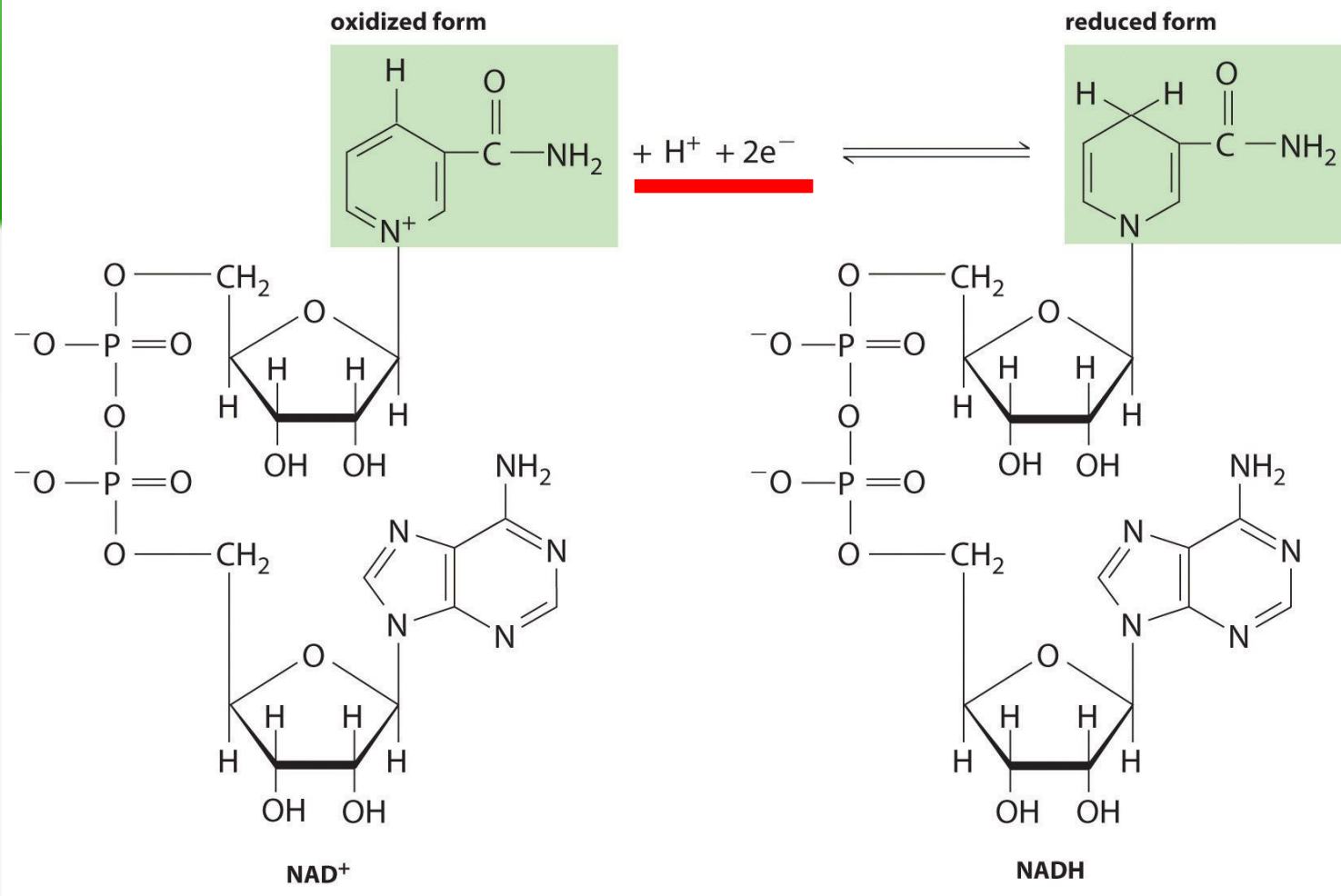
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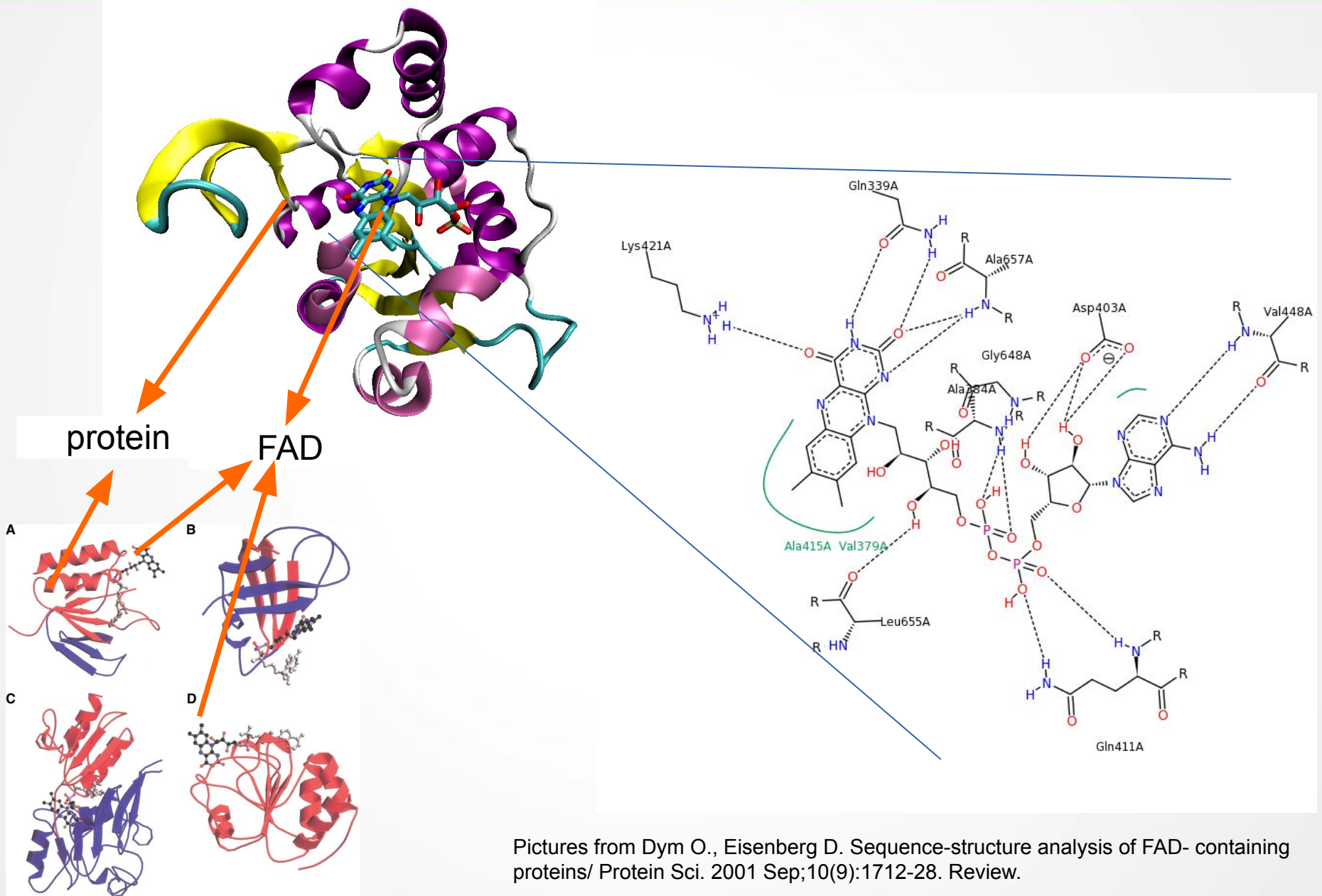
1. Introduction

Enzymes continue to be the subject of intensive research efforts because of their ability to accelerate chemical reactions by factors as large as 10^{20} with extraordinary selectivity.¹ Despite enormous advances, on both experimental and theoretical fronts, our understanding of how

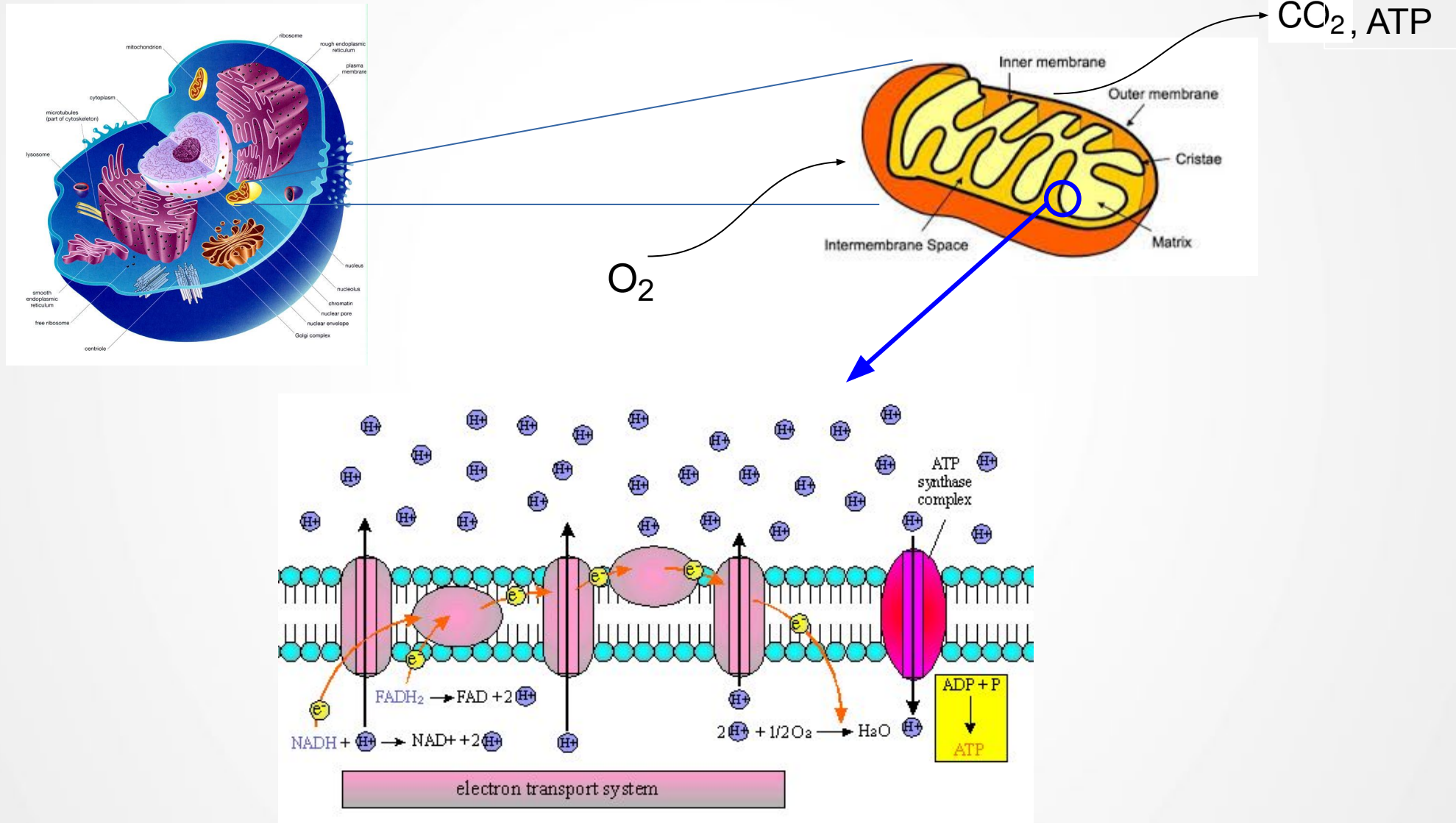




FAD- containing proteins



Electron transport system in mitochondria



Magnetoreception in Animals

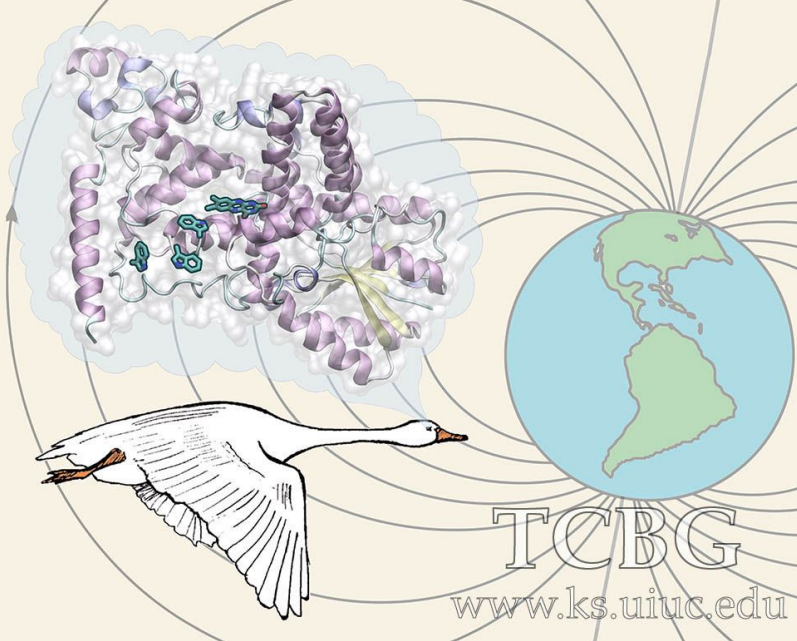
Magnetoreception exists in a wide variety of animals, including migratory birds, sea turtles, bees, mollusks, fish, salamanders, and bacteria.



First experiments were performed in the 1960s with homing pigeons and migratory birds

Magnetic Orientation in Migratory Birds

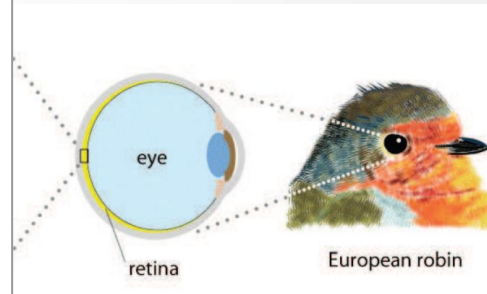
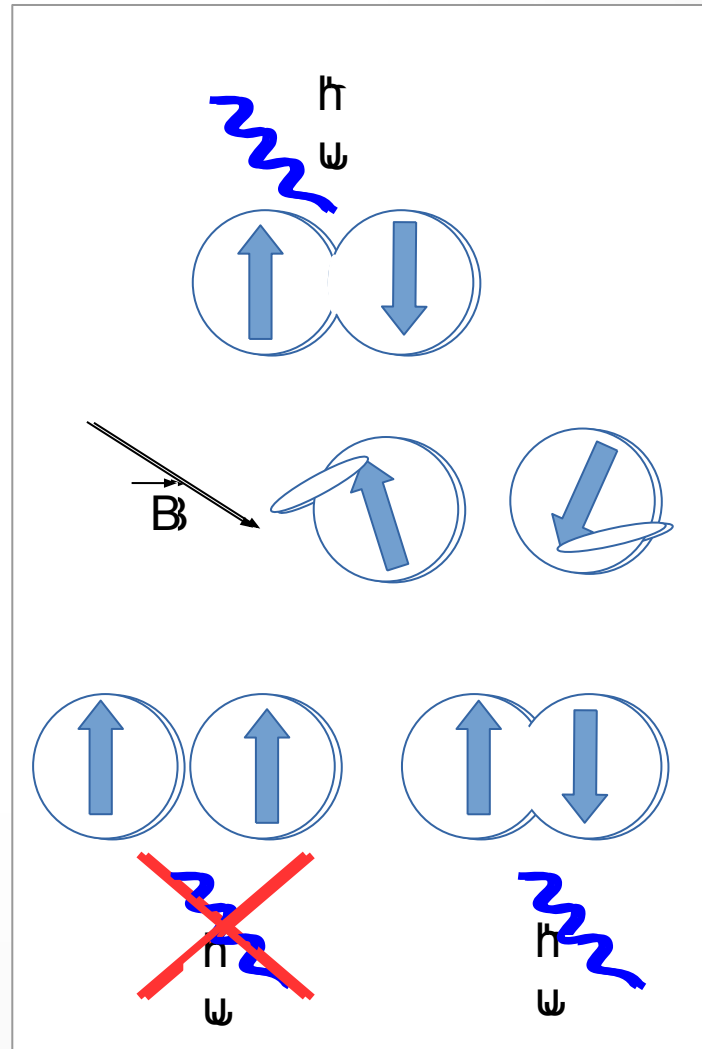
- Radical Pair Mechanism



Ilia A. Solov'yov

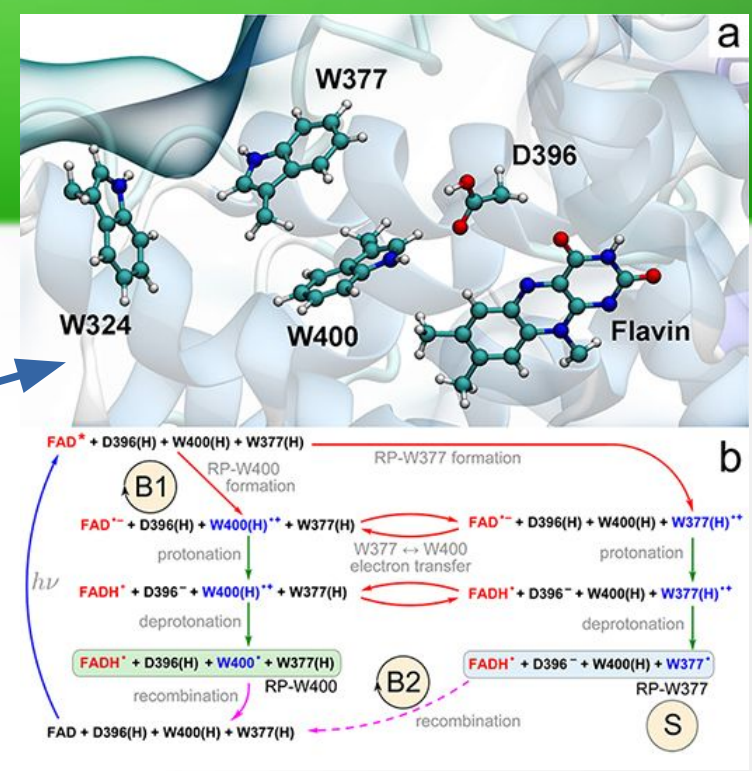
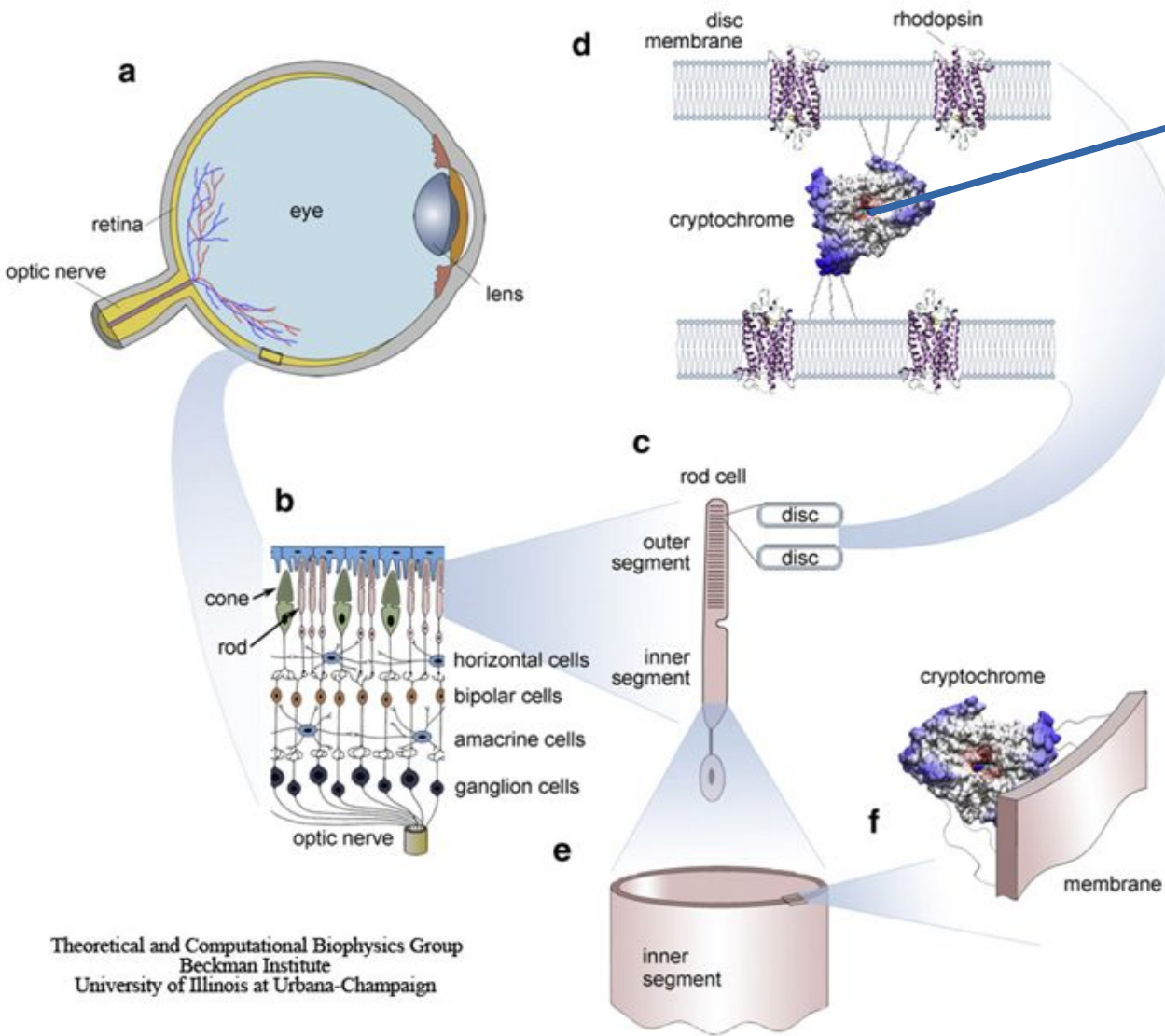


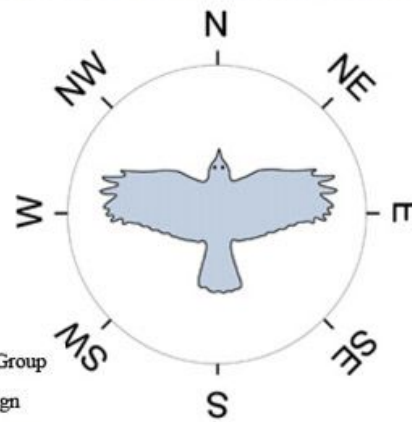
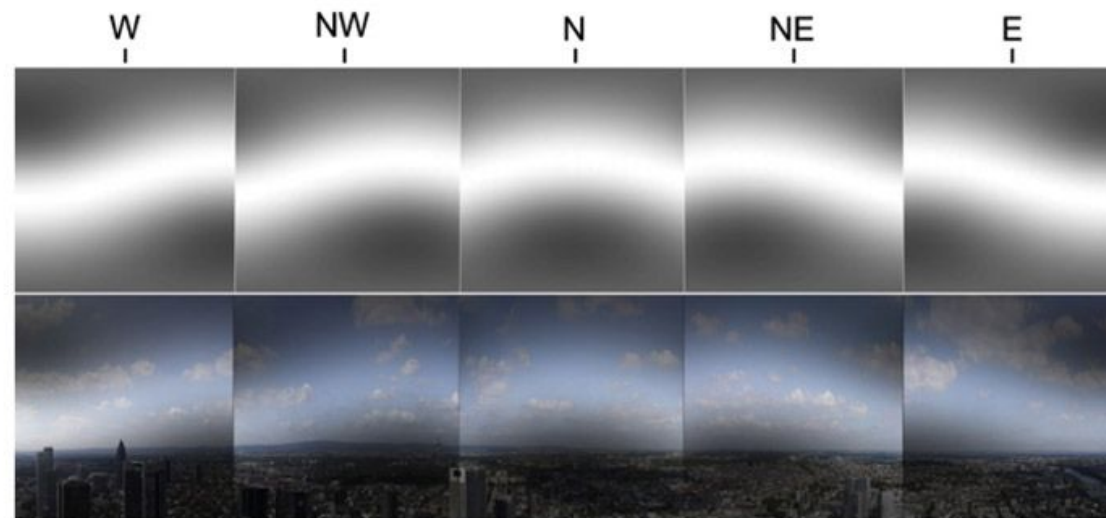
Klaus Schulten



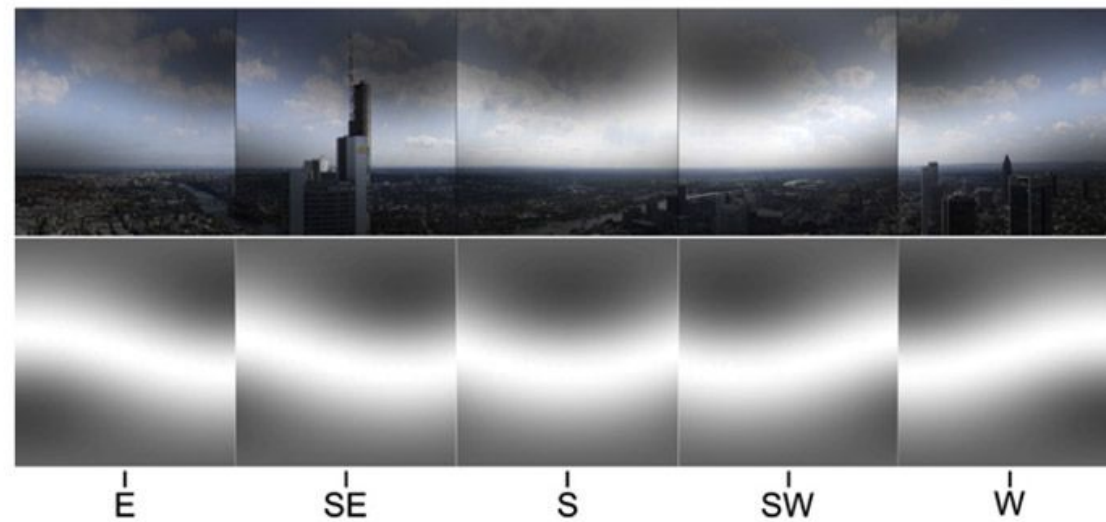
European robin



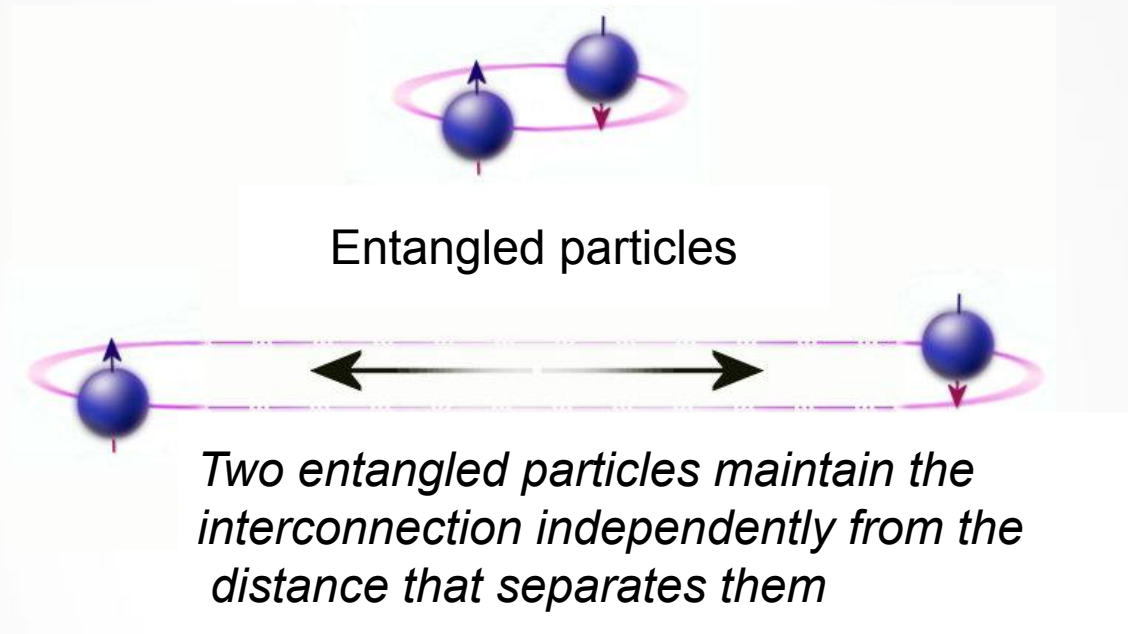




Theoretical and Computational Biophysics Group
Beckman Institute
University of Illinois at Urbana-Champaign



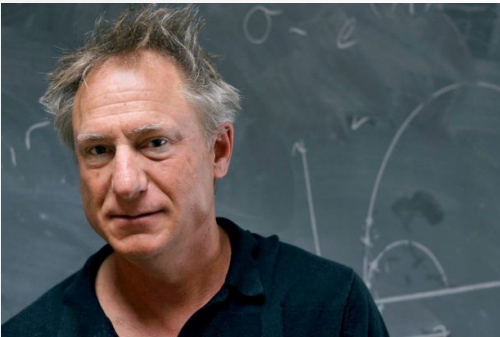
Quantum Entanglement



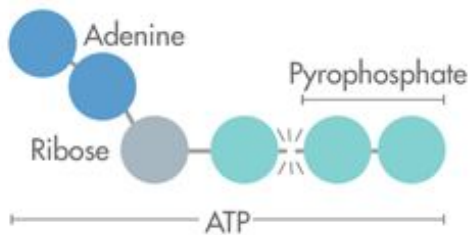
So if one particle is disturbed, the other is also disturbed

As an example, consider two electrons that have become entangled as a result of an interaction

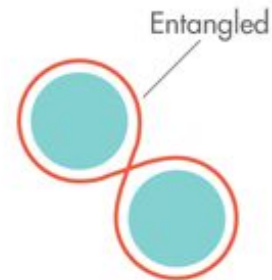
Is there a quantum basis for brain function?



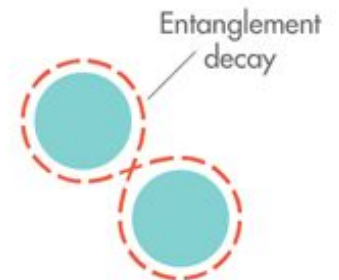
Matthew Fisher



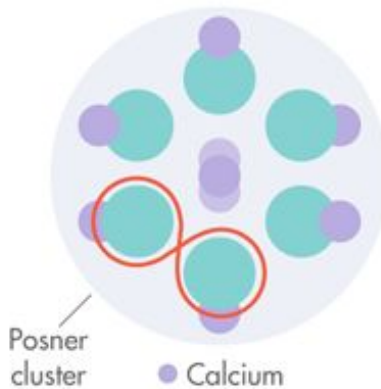
① The biological molecule adenosine triphosphate (ATP) can release pyrophosphate, made from two phosphate molecules.



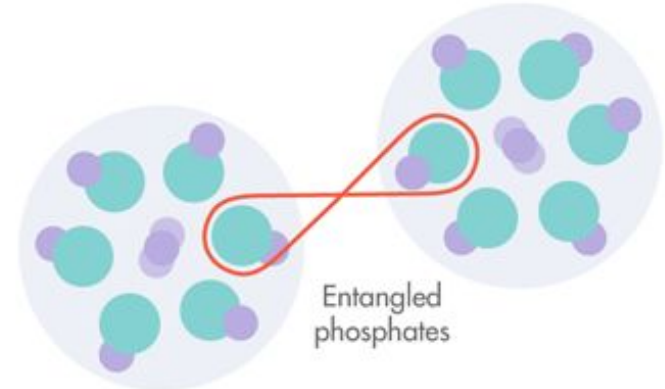
② Each phosphate carries a quantum spin, and the two phosphates can become entangled with each other.



③ Unprotected, the phosphate entanglement will decay, or decohere, in short order.



④ But if the phosphates are grouped together into protective clusters called Posner clusters, which are made of phosphate and calcium ions, the entanglement might survive for a longer time.



⑤ If a pair of entangled phosphates split into different Posner clusters, they will remain entangled even as the clusters transport them far from each other. In this way, the entanglement can be distributed over fairly long distances in the brain. This allows for the possibility of a quantum basis for brain function.