Coherent dynamics in solar energy transduction

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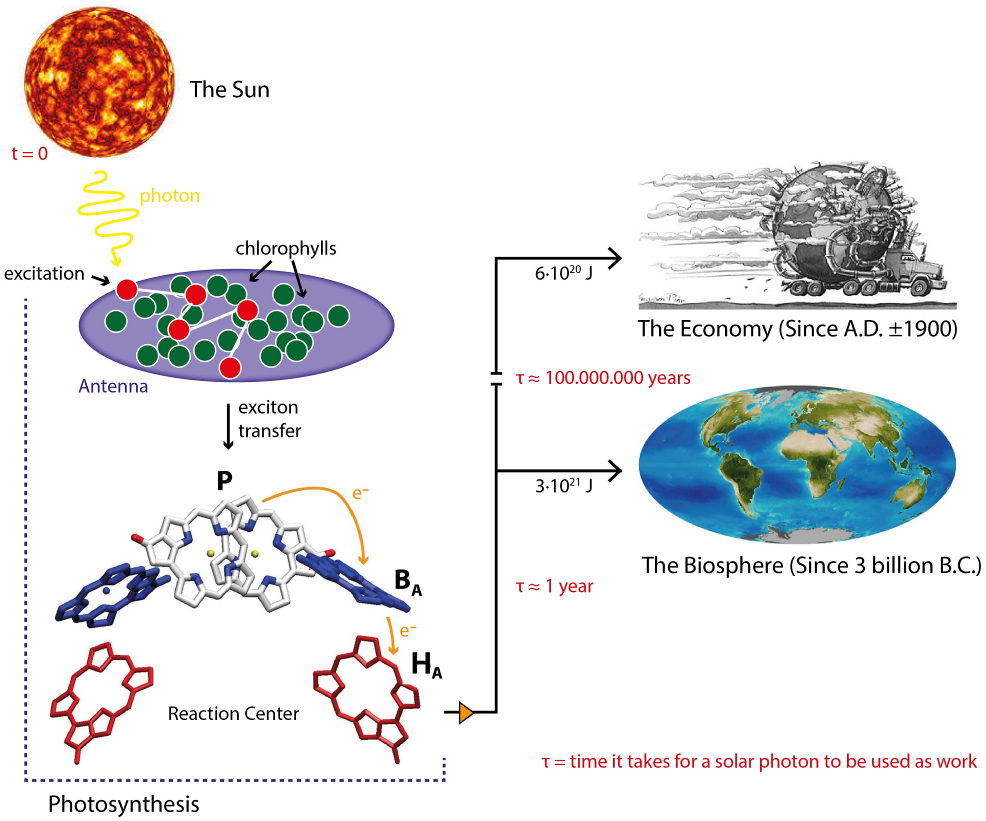
Summary

The motivation for this work is the Energy Conundrum depicted below. Simply stated, all energy on earth comes from the sun and is emitted through radiation.[1] This energy is used to power both the economy and all living organisms, collectively referred to as the biosphere. The light-to-electricity conversion is the crucial step in the energy transduction and is performed by photosynthesis. The time it takes between the emission of solar radiation and the utilization of the energy in the economy is approximately a hundred million years. In the biosphere the same is achieved within a single year.



[1]Nuclear energy excluded.

Coincidentally, the energy conundrum started taking shape at the same time (A.D.±1900) as the fundamental physical description of light and matter that is the theory of Quantum Mechanics. The prefix quantum was added to Newton's theory of mechanics to represent the fact that light and matter consist of specific quantum states that do not form a classical continuum. Oddly, a quantum system can be in multiple states simultaneously called a *superposition*. Sunlight consists of quantum mechanical packets of energy, photons. These can only be absorbed when their energy matches the energy difference between two quantum mechanical states of matter. Considering the building blocks of matter, positive nuclei and negative electrons, the higher energy state of matter that is populated by the absorption of a photon is a positive nucleus surrounded by a high energy electron collectively called an exciton.

The exciton is of no practical use for generating electricity. Left alone, this higher energy state will lose its energy and decay back to the original state through the emission of a photon. The challenge is to populate a different quantum mechanical state where the high energy electron is spatially separated from the positive nucleus, a so-called charge transfer state.[2] As nuclei are much heavier then electrons their movements are usually disregarded during the separation of charges. The crucial point in this thesis is that nuclear movements need to be accounted for as they drive the transitions between quantum states and ultimately determine the efficiency of solar energy transduction. Nuclear motion is said to be *coherent* when it induces a superposition of quantum states. In photosynthesis, evolution has optimized solar energy transduction by developing complex molecular structures that preserve coherence and allow single nuclear vibrations to drive the highly efficient separation of charges (**Chapters 3 and 4**). The condition for nuclear motion to coherently drive one state into another is called *resonance* and involves a matching of the energy contained in the vibration and the energy difference between the states. When satisfied, the energies of the states cross with the frequency of the coherent vibration and the initial state is gradually transformed into the final state (**Chapter 5**).

In summary, quantum technologies for solar energy transduction beyond the classical efficiency limit are possible (**Chapter 8, Outlook**). Left unpatented, such technologies can raise living standards and promote equality.

[2]Once this challenge is met an electric current can be generated from the negative to the positive regions. The economy can be imagined as a resistance in this electrical circuit and its energy demands can be directly supplied from the sun.