Entanglement-enhanced Efficient Energy Transport

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March 12, 2010
Light-Harvesting
Absorption of A Photon And Transfer to An Reaction Center

light-to-charge efficiency > 95% !
energy shuttle
Fenna-Matthews-Olson (FMO) complex
precise functionality more or less unknown...

scope of this talk are quantum mechanical effects involved?
And if so, is the efficiency a result thereof?
Coherent Versus Incoherent Transport

- **Experimental evidence** for coherence

- **Recent approach** suppress coherence, decoherence as transport amplifier
  A. Chin et al., *arXiv*:0910.4153

- **Our approach** nature exploits coherence and evolved **optimal conditions**, where noise is **not responsible** for transport efficiency
Physical Abstraction

Coherent Dynamics on A Fully Connected, Finite Graph

FMO ~ network of nodes

\[ \text{couplings } V_{i,j} \propto r_{i,j}^{-3} \]

\[ \text{start } |\psi(0)\rangle = |\text{in}\rangle \]

\[ \text{destination } |\text{out}\rangle \]

\[ \text{disorder } \text{intermediate nodes uniformly distributed within sphere} \]
Transport Efficiency

Time Evolution of On-site Probabilities $p_i = |\langle i | U(t) | \text{in} \rangle|^2$

Time until $\mathcal{T} = \pi / (20 |V_{\text{in,out}}|)$
Maximal Transport Efficiency

Fluctuations of 1000 Realizations

roughly 1 in a million configurations has an efficiency $p_{\text{out}}^{\text{max}} > 90\%$
Entanglement Evolution

Time Evolution of Global 2-particle Entanglement $\tau_2(\psi(t)) = \sqrt{\frac{1}{1-1/N} \left(1 - \sum_{i=1}^{N} p_i^2(t)\right)}$

time where $p_{\text{out}} = p_{\text{out}}^{\text{max}}$
Efficiency Relies on Entanglement

low efficiency can be achieved with any deal of entanglement

high efficiency requires high entanglement
Efficiency Relies on Entanglement

joint probability density

many-body entanglement is absolutely essential for efficient transport

maximal efficiency $p_{\text{out}}^{\text{max}}$

3-particle entanglement $\tau_3^{\text{max}}$
Penalties Due to Decoherence

local dephasing rate $\gamma = 0.6/T$

maximal efficiency $p_{\text{out}}^\text{max}$

random spatial conformations
optimal conformations induce coherent efficient transport
decoherence does not change this
efficient transport implies build-up of strong entanglement

universality results independent of actual interaction type

\[ V_{i,j} \propto r_{i,j}^{-q}, \]
\[ V_{i,j} \propto e^{-\alpha r_{i,j}}, \]
\[ V_{i,j} \text{ Gaussian Random Variables} \]

arXiv:0912.3560
“That’s all Folks!”