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Quantum Biology

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Outline

- Introduction
- Exploring the Boundary: Matter-wave Interference of a Native Polypeptide
- From Fermi's Golden Rule to Tunneling in Enzymatic Reactions
- Other Examples
  - Photosynthesis
  - Avian Magnetoreception
- Discussion

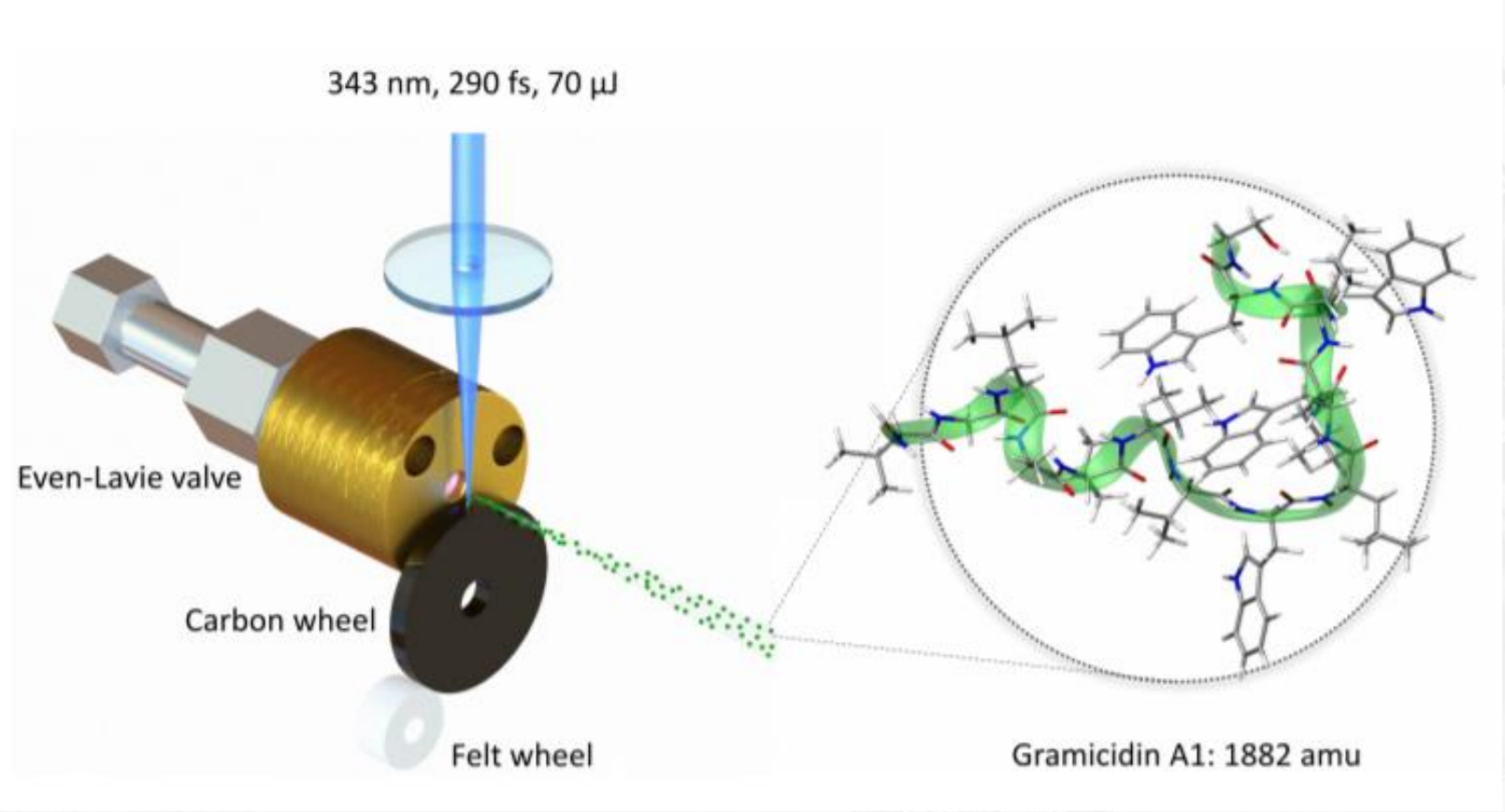
Introduction

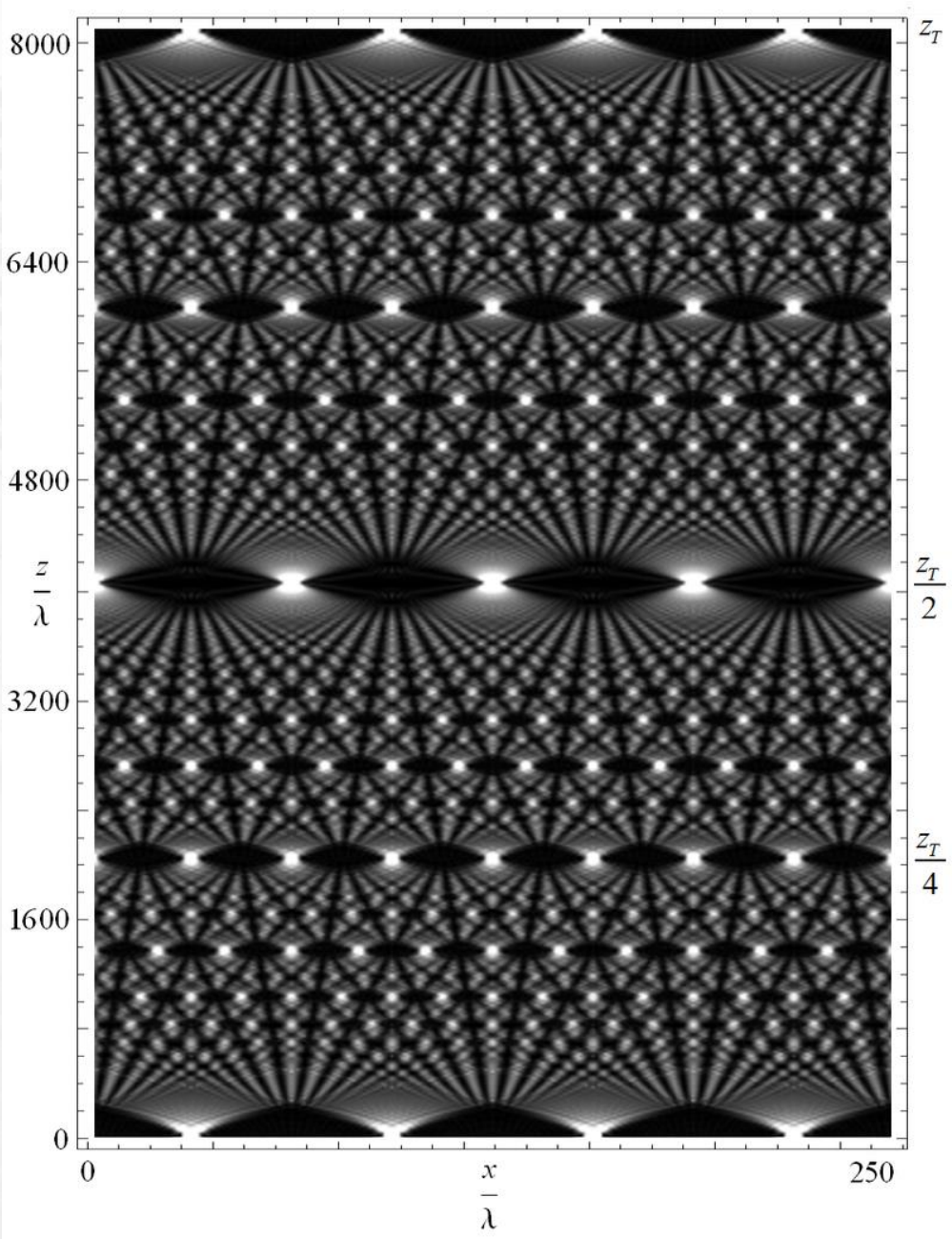
To be brief……

“Not only does quantum theory apply to these biological systems, but it’s possible to test whether these systems are harnessing quantum physics to perform their functions.”

——Chiara Marletto, University of Oxford

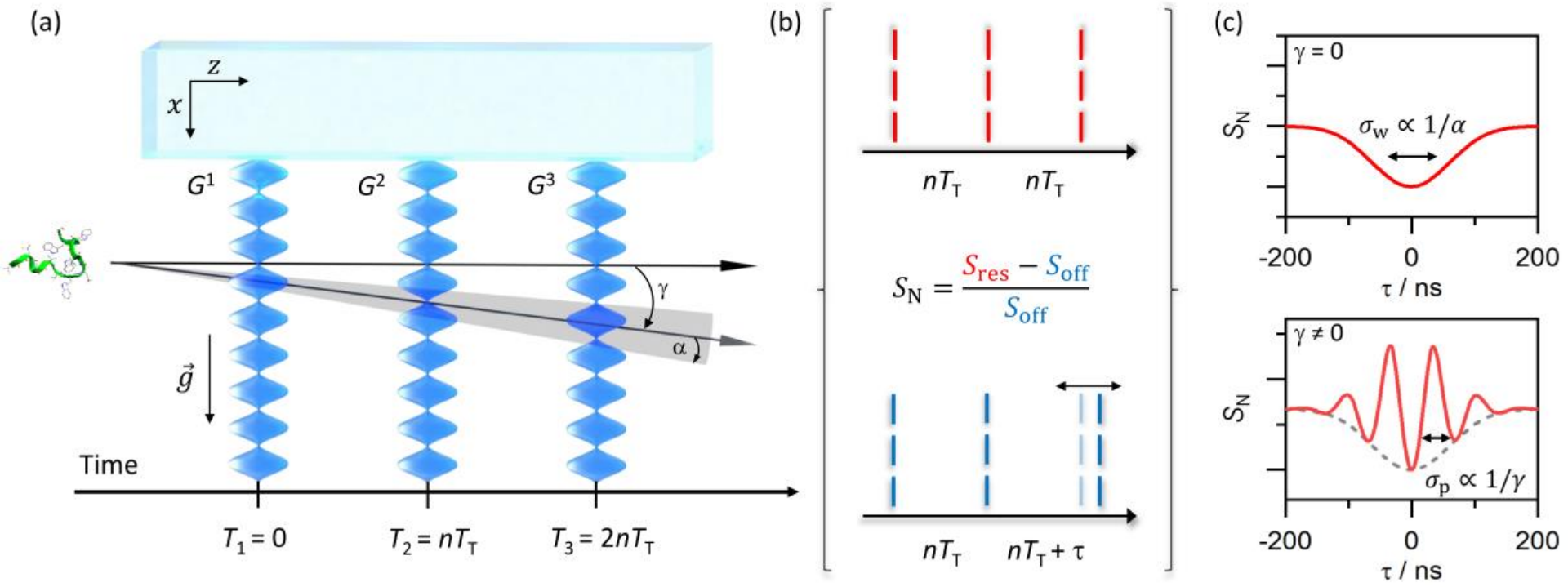
Matter-Wave Interference of a Polypeptide





$$Z_T = \frac{2d^2}{\lambda}$$

Matter-Wave Interference of a Polypeptide



$$nT_T = n\frac{md^2}{h} \qquad (1)$$

The Wigner function is defined as the transformation of the position density matrix $\rho(x, x') = \langle x|\hat{\rho}|x'\rangle$

$$w\left(x, p_x\right) = \frac{1}{2\pi\hbar}\int ds\, e^{ip_x s/\hbar}\left\langle x - \frac{s}{2}\right|\hat{\rho}\left|x + \frac{s}{2}\right\rangle$$

Free propagation over a time t

$$w\left(x,p_x\right)\rightarrow w\left(x-\frac{p_x t}{m}+\frac{p_\gamma t}{m}+\frac{gt^2}{2},p_x-p_\gamma-amt\right)$$

Transmission through a grating is described by the convolution of the Wigner function and the transmission kernel

$$w\left(x,p_x\right)\rightarrow\int dp_0\;T^{(\mathrm{k})}\left(x,p_x-p_0\right)w(x,p_0)$$

$$T^{(\mathrm{k})}(x,p_x)=\frac{1}{2\pi\hbar}\sum_n \exp\left(\frac{2\pi i n x}{d}\right)$$
$$\times\int ds\, e^{ip_x s/\hbar} B_n^{(\mathrm{k})}\left(\frac{s}{d}\right),$$

$$B_n^{(\mathrm{k})}(\chi)=\exp\left(\frac{-n_{0,\mathrm{eff}}^{(\mathrm{k})}}{2}\right)\left(\frac{\sin(\pi\chi)-\beta\cos(\pi\chi)}{\sin(\pi\chi)+\beta\cos(\pi\chi)}\right)^{\frac{n}{2}}$$
$$\times J_n\left(\mathrm{sign}\left(\frac{\sin(\pi\chi)}{\beta}+\cos(\pi\chi)\right)\frac{n_{0,\mathrm{eff}}^{(\mathrm{k})}}{2\beta}\sqrt{\sin^2(\pi\chi)-\beta^2\cos^2(\pi\chi)}\right),$$

Classically:

substituting $\sin(\pi\chi)\to\pi\chi$ and $\cos(\pi\chi)\to 1$

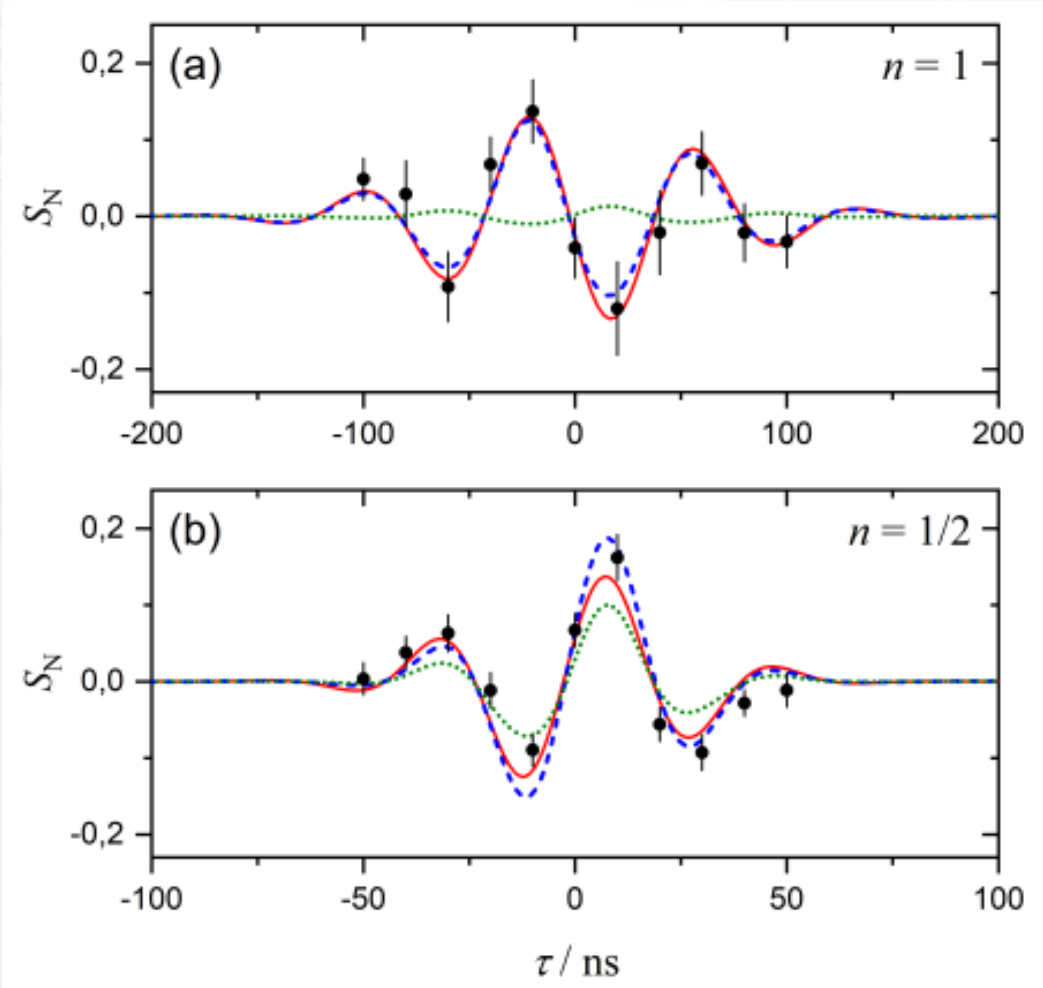
Convolution of $w_4(x)$ with the transmission Kernel $T_3(x,p)$and integration over the whole phase space

$$S\left(\Delta x\right)=\sum_{l}S_{l}\ \exp\left[\frac{2\pi il}{d}\Delta x(\Delta x_{\mathrm{s}},T,\tau)\right],$$

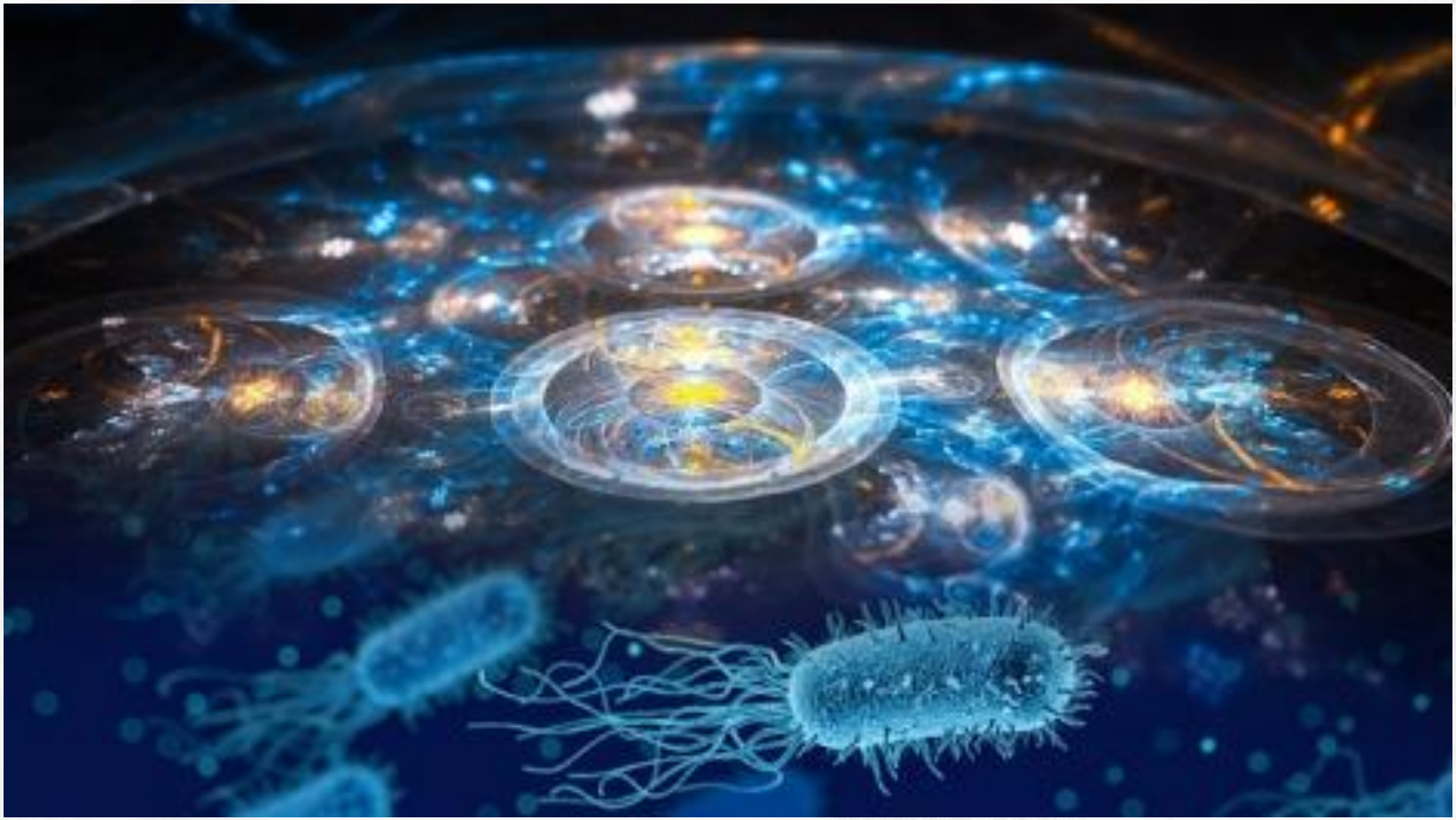
$$S_{l}=\widetilde{D}\left(\frac{l\tau}{T_{\mathrm{T}}}d\right)B_{-l}^{(1)}\left(0\right)B_{2l}^{(2)}\left(\frac{l\left(T+\tau\right)}{T_{\mathrm{T}}}\right)B_{-l}^{(3)}\left(0\right)$$

Matter-Wave Interference of a Polypeptide

$$S_N = V_0 \exp\left[-\left(\frac{\tau}{\sigma_W\sqrt{2}}\right)^2\right]\cos\left(2\pi\frac{(\tau-\tau_{off})}{\sigma_P}\right) \quad (5)$$



Matter-Wave Interference of a Polypeptide

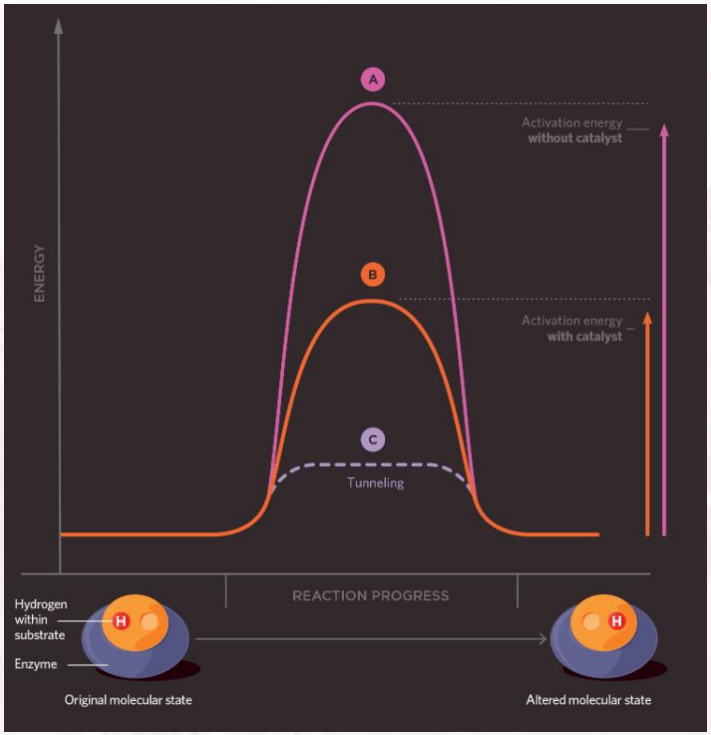


Next: Schrodinger's Bacteria?

Tunneling in Enzymatic Reactions

Classical

$$k = k_{\infty} \exp\left\{\frac{-\Delta E^{\ddagger}}{k_{\mathrm{B}} T}\right\}$$

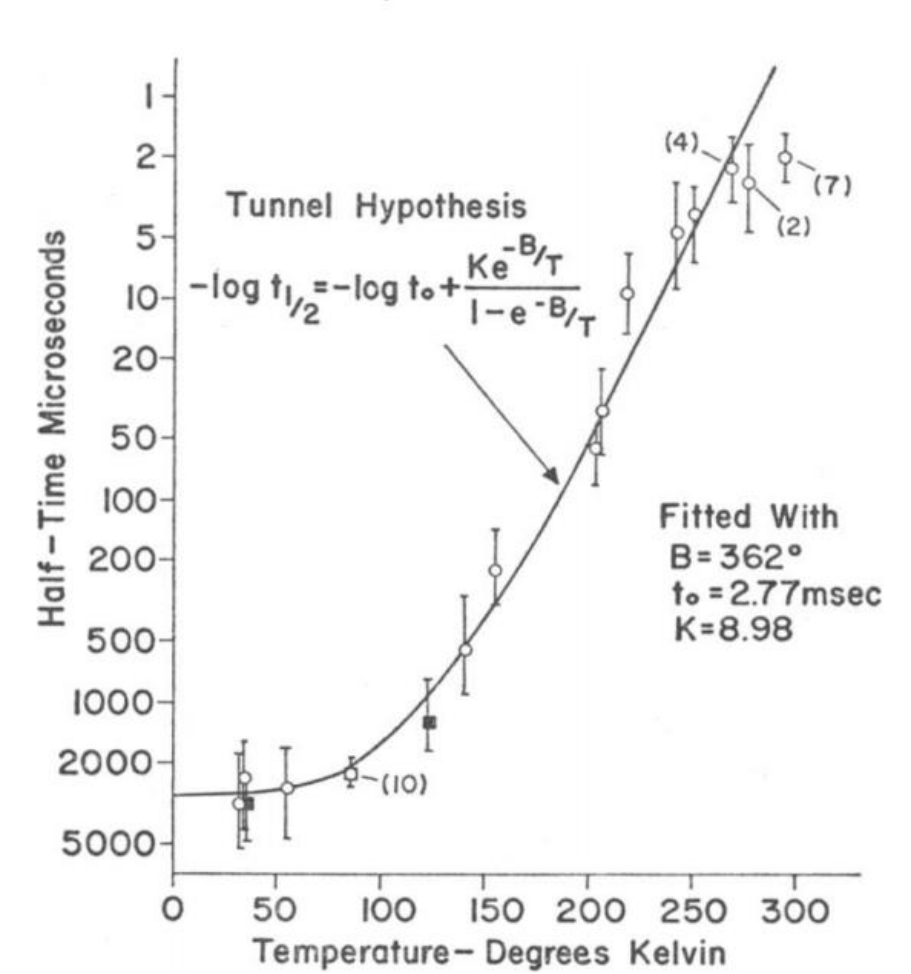


Quantum

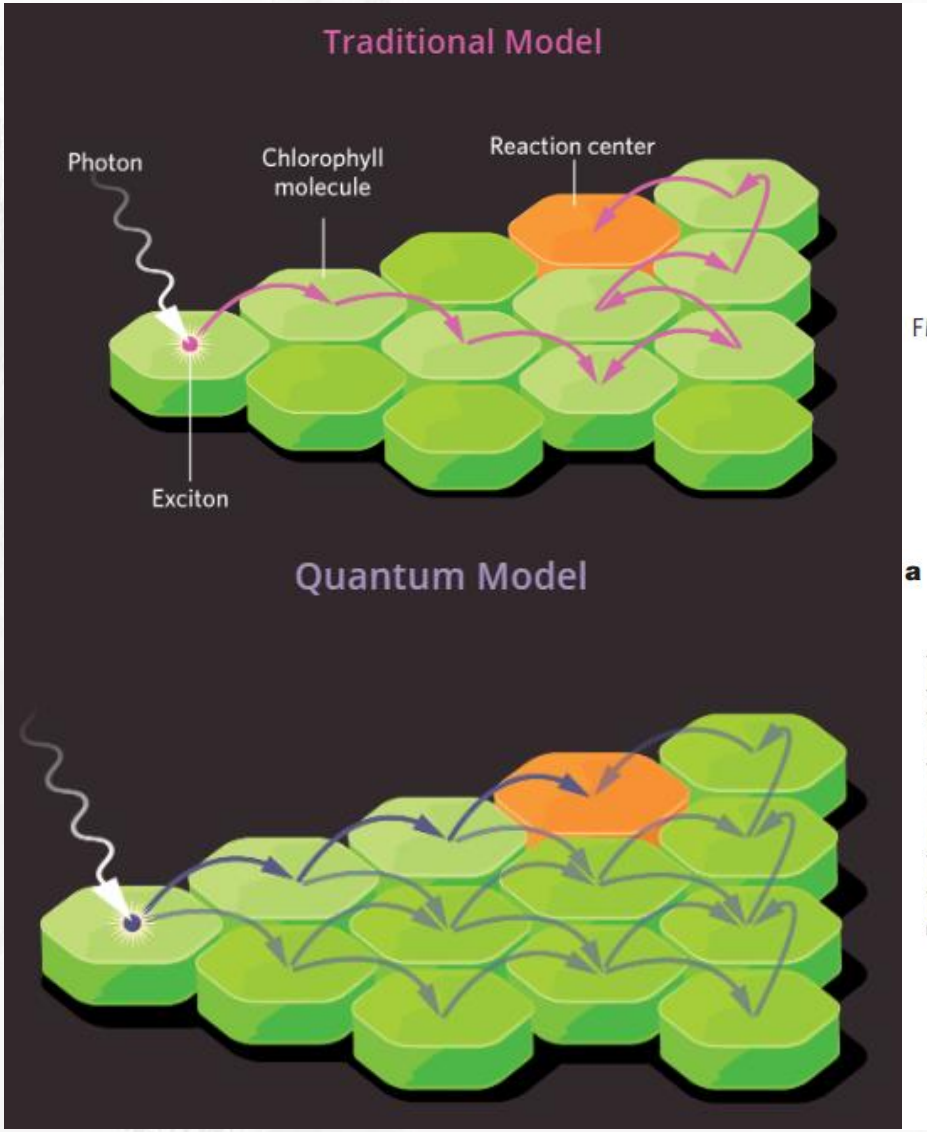
$$\mathrm{rate}(D \rightarrow A) = \frac{2\pi}{\hbar} |H_{\mathrm{DA}}|^2 \rho$$

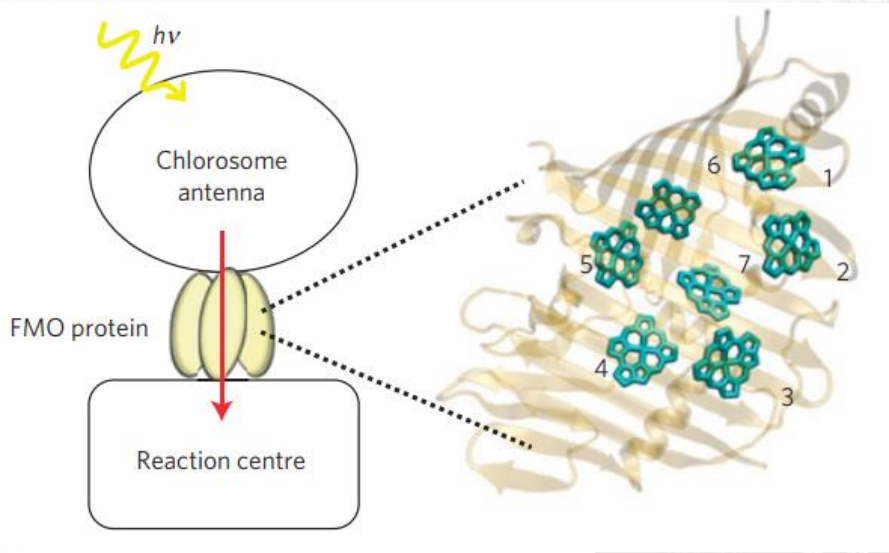
$$k_{\mathrm{DA}} = \frac{2\pi}{\hbar\omega} |H_{\mathrm{DA}}|^2 \exp^{-S(2n+1)} \left\{\frac{\tilde{n}+1}{\tilde{n}}\right\}^{1/2p} I_P(2S[\tilde{n}(\tilde{n}+1)]^{1/2})$$

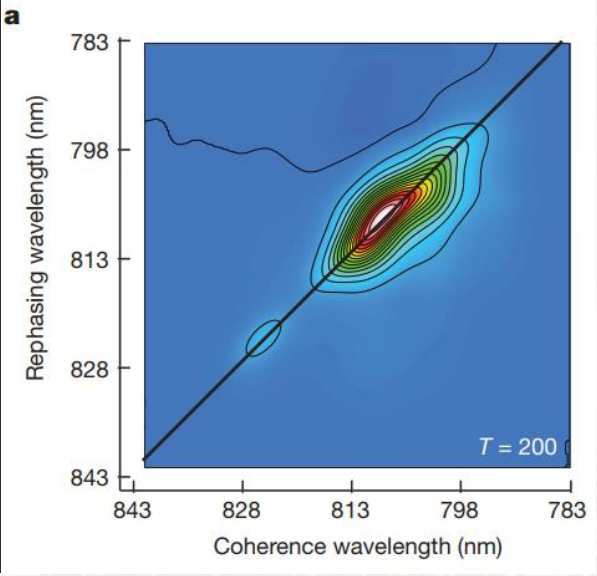
Tunneling in Enzymatic Reactions



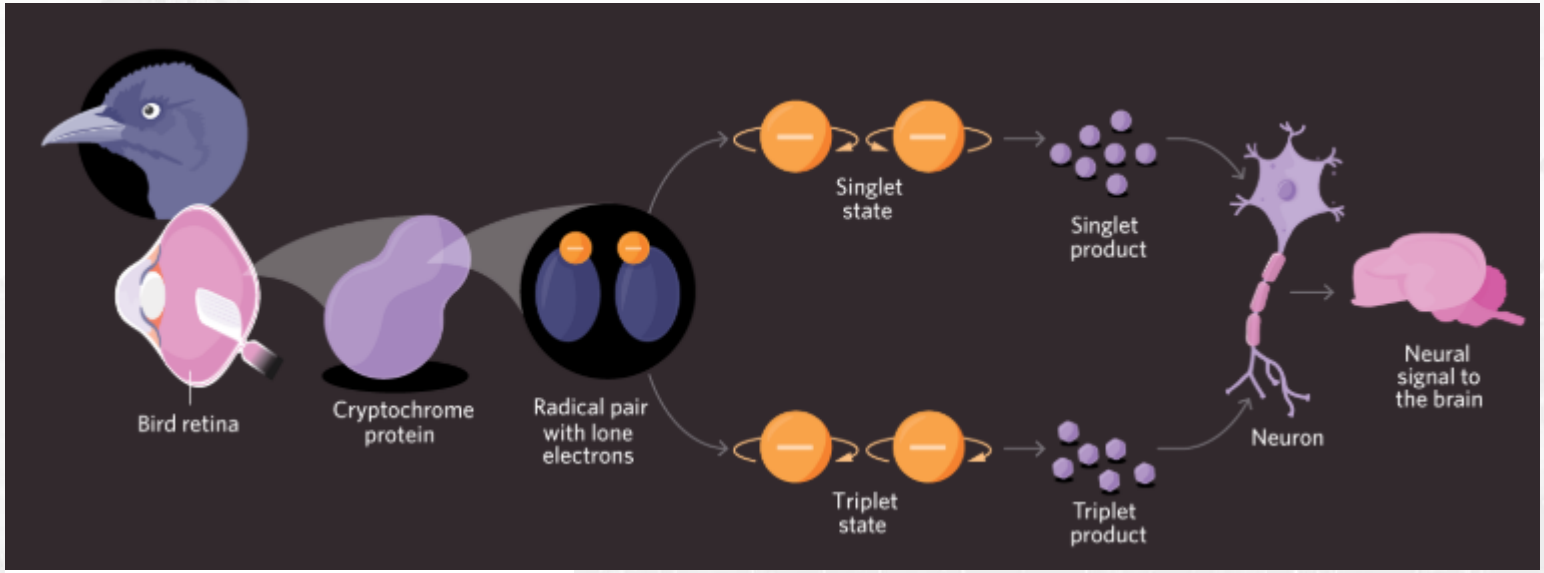
Photosynthesis

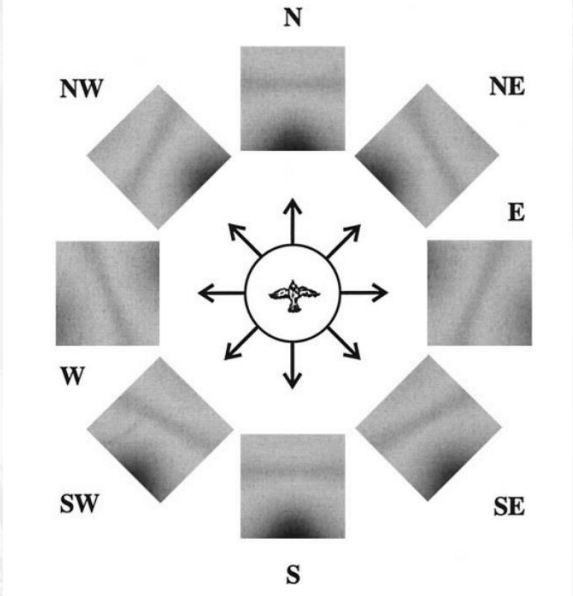






Magnetic Compass





Discussion

· The Golden Rule's description is under doubt because lacking knowledge of what D/A states really are.

· More experimental evidence in need.

· It's hoped that some theory and concepts highlight promises, and developments will continue.

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