Electron Tunneling as Trigger for Conformal Changes in Cerebral Microsites

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Flagstaff, July 1999

<u>Program</u>

1. **Introduction: The Essence of Quantum Brain**

2. **Energy/Time Scales: The Macro/Micro Regimes**

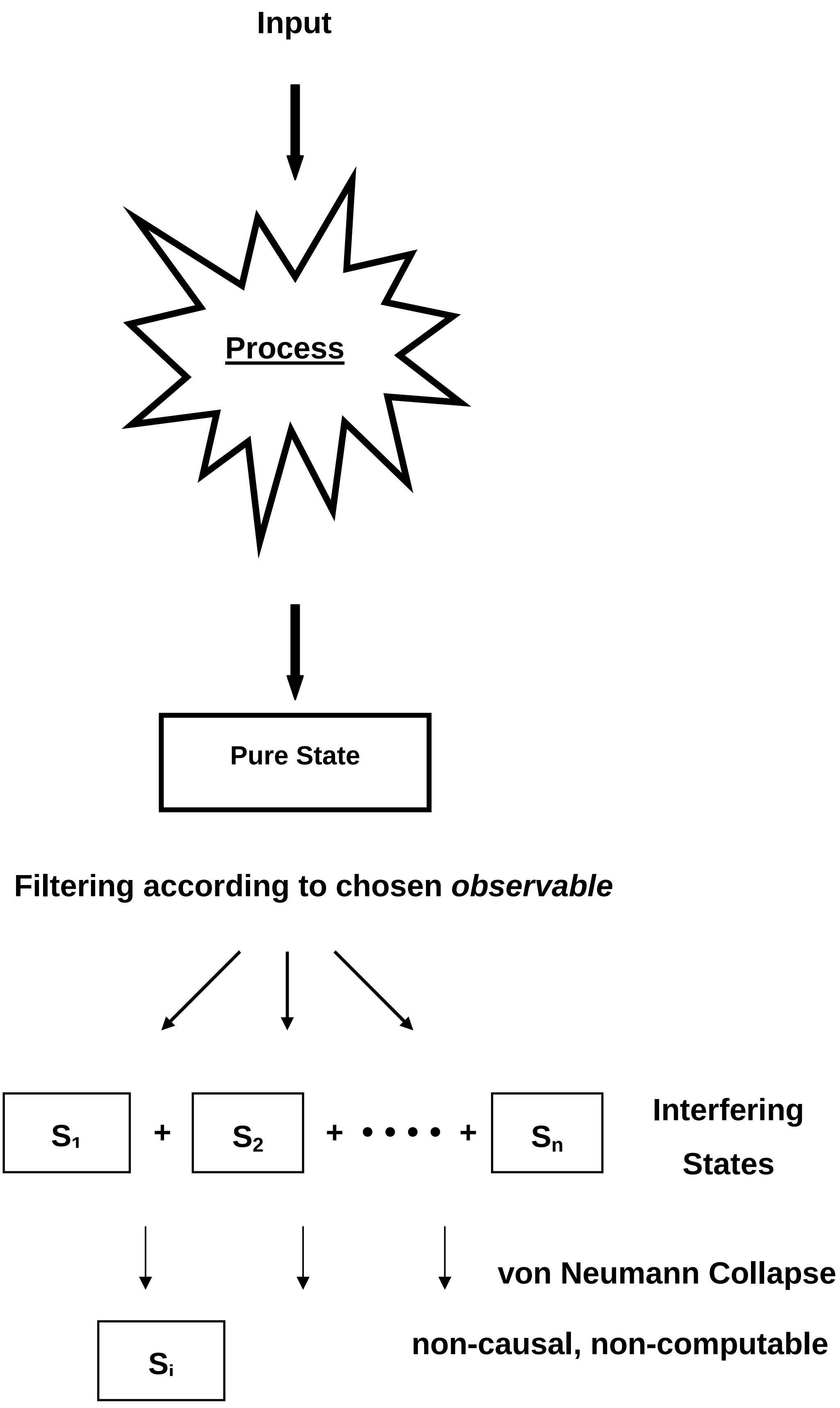
3. **Neural Regulators: Synapses and Tubulin Proteins**

4. **Electron Tunneling: Trigger for Conformal Changes**

5. **The Binding Problem: Spatio-temporal Coherence**

6. **Conclusions**

1. The Essence of Quantum Brain



2. Energy/Time Scales: The Macro/Micro Regimes

***Macrostructure*:** ***hot* and *wet* medium**

T $>$ 300 ^{o}K → *thermal fluctuations*

Microstructure: ***embebbed* into this medium**

quantum states coupled to a dissipative system !

Complex Structures: search for *time scales* separating dynamics

Two characteristic energies:

(*i*) *thermal energy*

$$\boxed{E_{th} = \tfrac{1}{2}\, k_B\, T}$$

(*ii*) *quantal energy* ***quasiparticle*, mass m_{eff}, localization Δq**

$$\boxed{E_{qu} = \frac{(\Delta p)^2}{2\, m_{eff}} = \left(\frac{2\pi\hbar}{\Delta q}\right)^2 \frac{1}{2 m_{eff}}}$$

breaking point: $E_0 = E_{qu} = E_{th}$

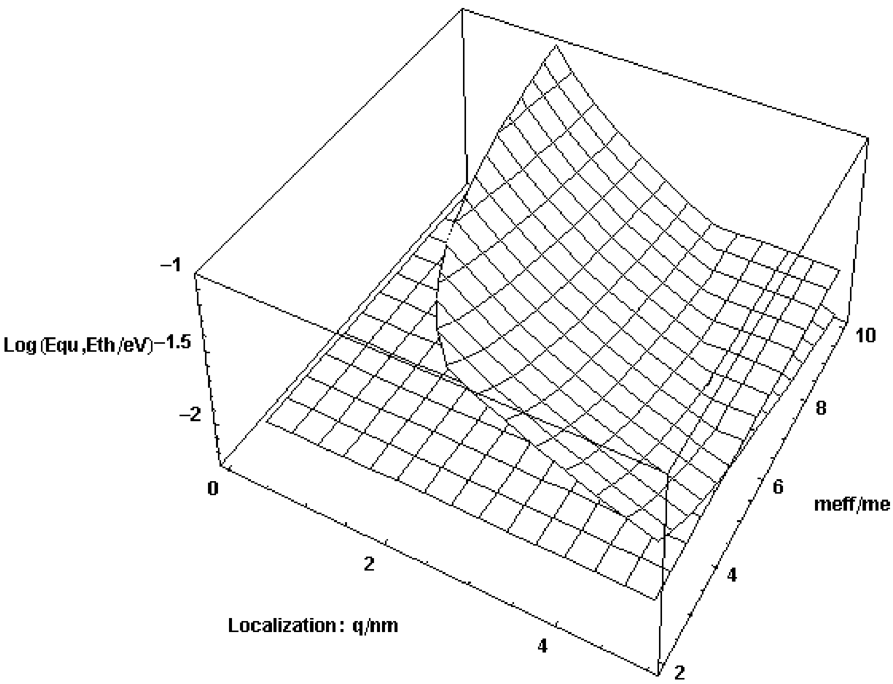
$E_{qu} \ll E_0$ ***thermal regime***

$E_{qu} \gg E_0$ ***quantal regime***

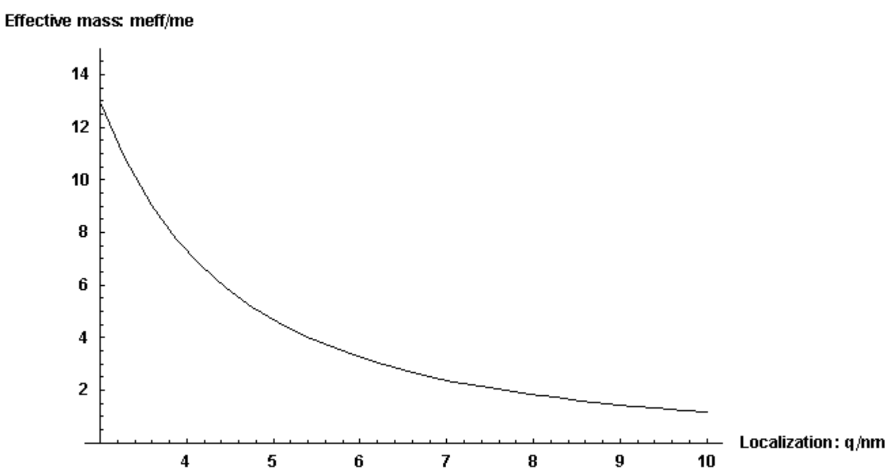
at *physiological temperature:* $E_0 \cong 1.3 \cdot 10^{-2}$ eV

Numbers:

Localization* in biological *microsites $\Delta q \sim 3-4\ n$



Effektive mass at breaking point $$m_{eff} = \left(\frac{2\pi\hbar}{\Delta q}\right)\frac{1}{2E_0}$$



Time scales

frequency at the breaking point $\omega_0 = \frac{E_0}{\hbar} = 2 \cdot 10^{13}\, s^{-1}$

signal time $\boxed{\tau_0 = 0.3 \text{ ps}}$

cellular dynamics ***cellular time*** $\boxed{\tau_c > 0.4 \text{ ns}}$

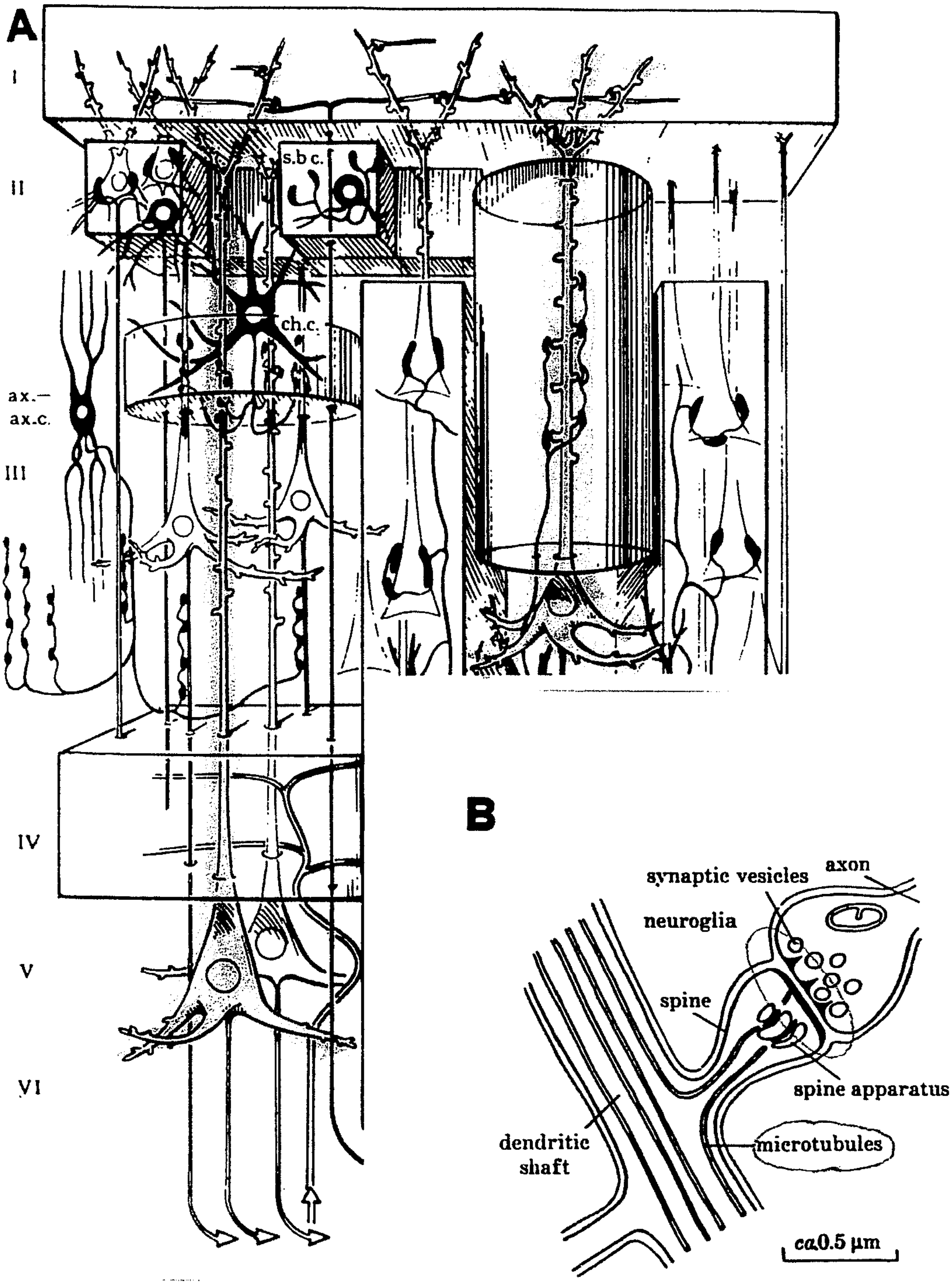
(*Tuszynski et al., 1998* : $E_{cell} \sim 10^{-5}$ eV)

well separated **time scales** ➔ ***dynamics decouples !***

3. <u>Neural Regulators: Synapses and Tubulin Proteins</u>

Symplified sketch of *cortical structure* (*Szentagothai, 1978*)

***switches* are *spine synapses* and *microtubules* (inset B)**

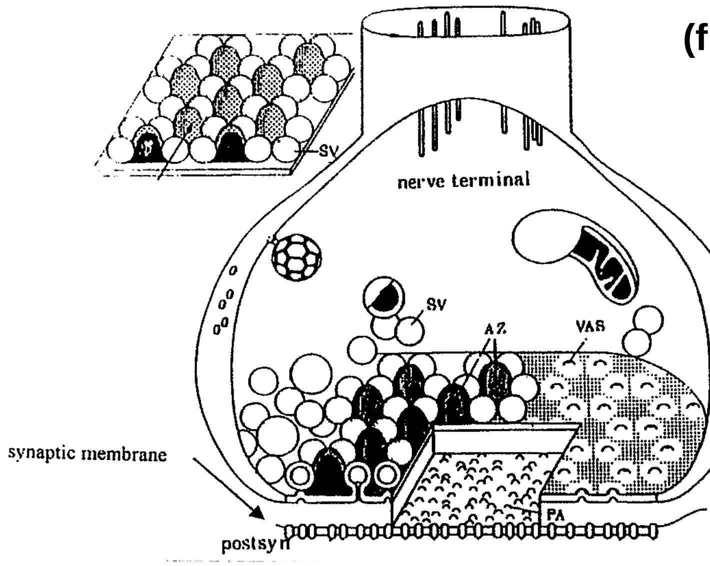


The quantal microsites (neural switches)

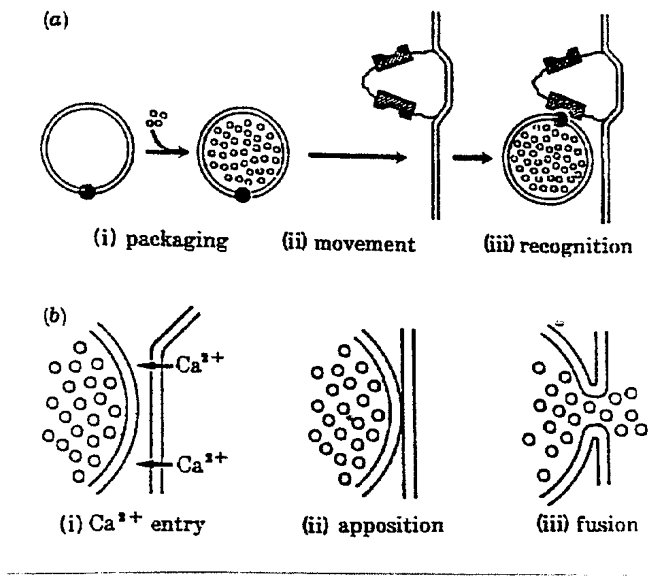
(a) Spine synapses (*Beck & Eccles, 1992*)

***Exocytosis* : Release of transmitter molecules through synaptic membrane**

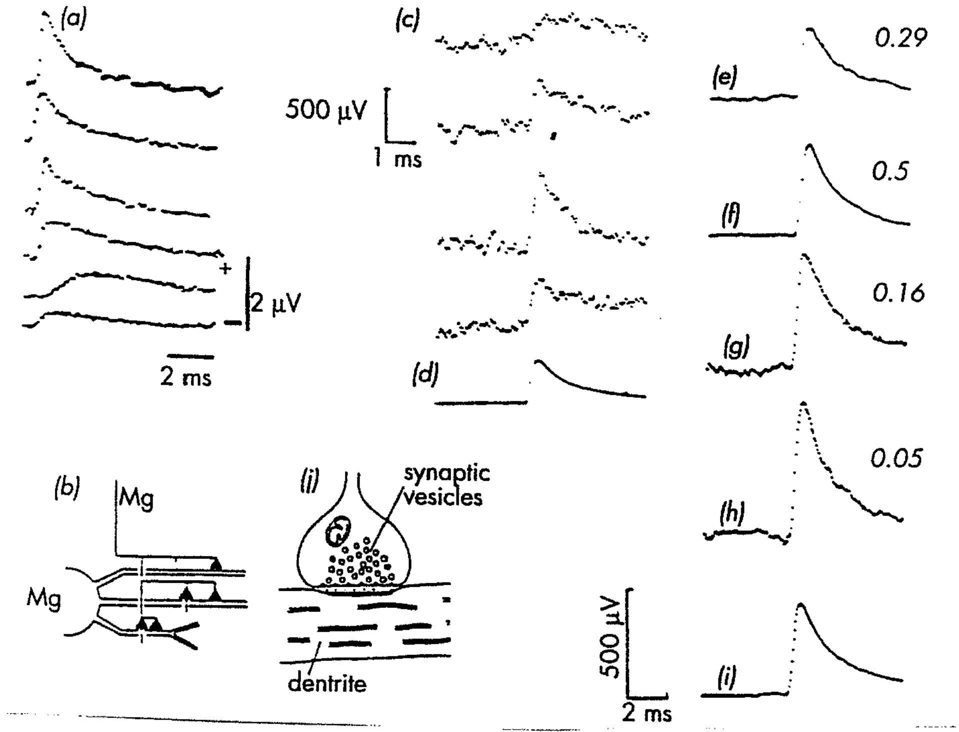
(from: *Akert et al., 1975*)



stages* of *exocytosis



Fluctuation analysis **of monosynaptic exocytosis (*Redman, 1990*)**

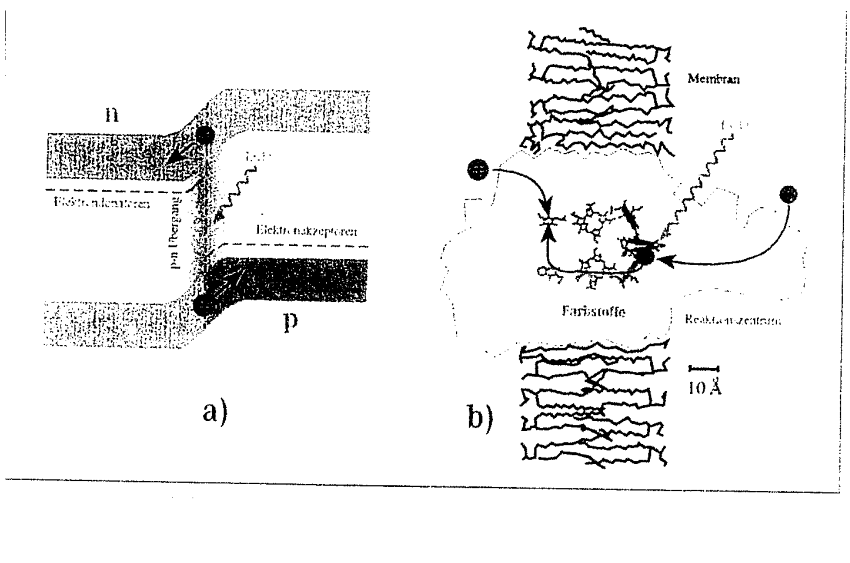


leads to *probabilities for exocytosis per incoming nerve impulse*

$$\boxed{p_{ex} \ll 1}$$

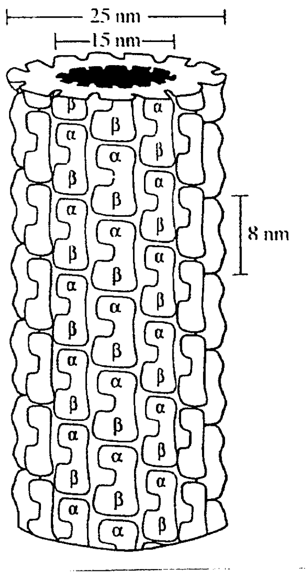
Exocytosis: ***Quantal mambrane transport process***

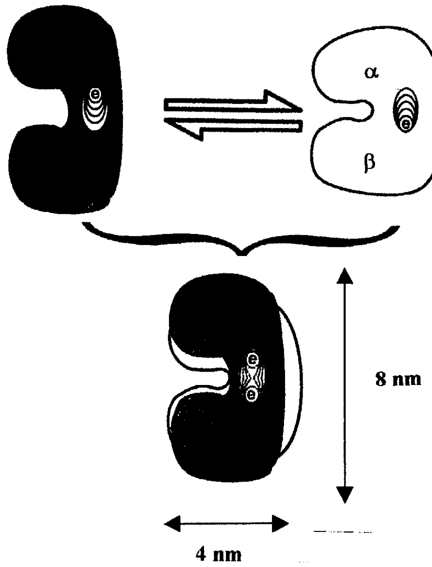
analogue*:** ***photobacterial reaction center **(*Vos et al., 1993*)**



(b) Tubulin dimer (*Hameroff & Penrose, 1994)*

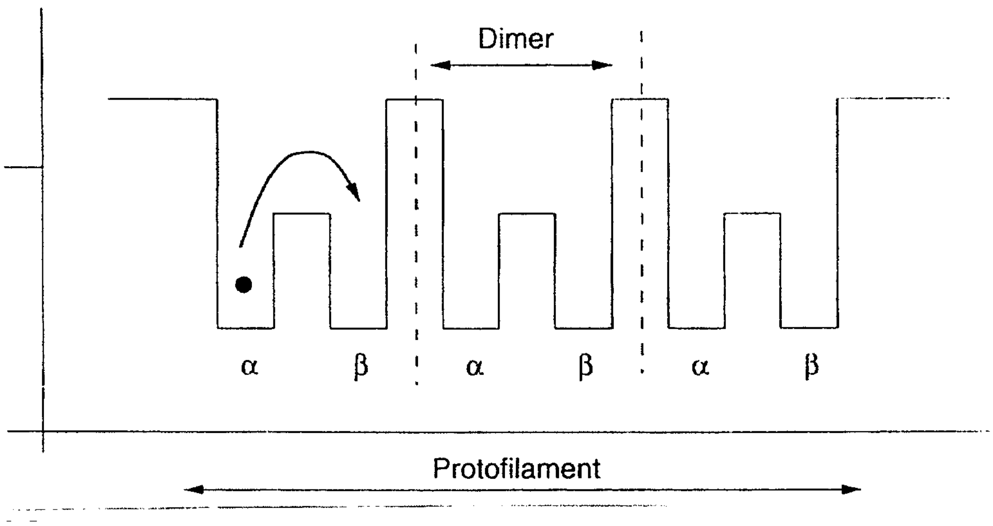
structure of *microtubules*





tubilin dimer molecule **two conformations:**

superposition of quantum states



model for electron transfer (*Tuszynski et al., 1989*)

4. Electron Tunneling: Trigger for Conformal Changes

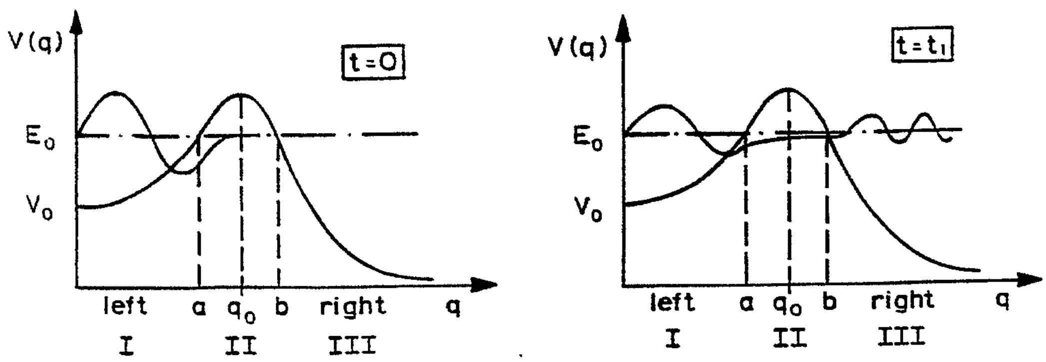
Synaptic filtering: ***initialized*** **by** ***electron tunneling*** **in the** ***activated presynaptic membrane***

Tubulin molecules: ***electron transfer*** **within** ***tubulin pocket***

Model: **electron coupled to molecular motion:** ***quasiparticle*****, mass** m_{eff} ***tunneling*** **through** ***activation barrier***

Solution of time-dependent ***Schroedinger equation*** **in potential** ***V(q)***

$$i\hbar \frac{\partial}{\partial t}\Psi(q;t) = -\frac{\hbar^2}{2M}\frac{\partial^2}{\partial q^2}\Psi(q;t) + V(q)\Psi(q;t)$$



at time t_1 **: end of** ***activation period***

decomposition **of the** ***wavefunction*** **into** ***two coherent parts***

$$\Psi(q;t_1) = \Psi_{left}(q;t_1) + \Psi_{right}(q;t_1)$$

after ***reduction*** **(von Neumann** ***collapse*****):**

probability **for** ***exocytosis*** **or** ***conformal change***

$$\boxed{p_{ex}(t_1) = \int |\Psi_{right}(q;t_1)|^2 \, dq}$$

Alternative description: *separation* of electron and nuclear coordinates

electron *coupled* to nuclear motion (Franck-Condon principle, Marcus theory of electron transfer)

***donor* D $\longrightarrow$ *acceptor* A : DA $\longrightarrow$ D^+A^-**

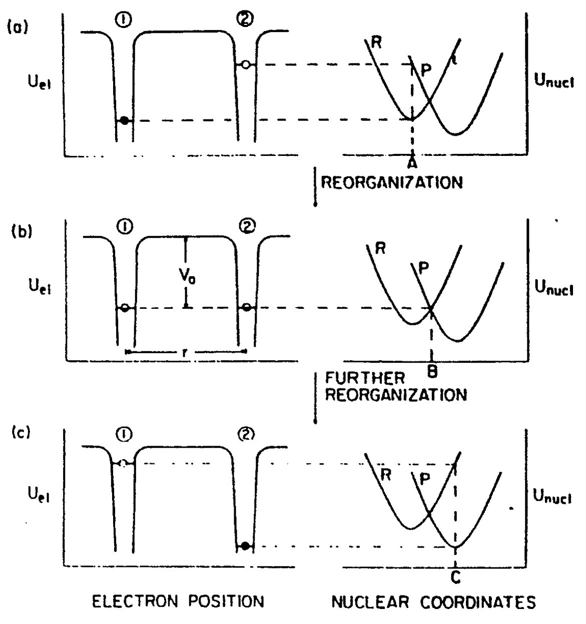
$\Psi_i \otimes \chi_i(q) \rightarrow \Psi_f \otimes \chi_f(q)$; ***q*** **: nuclear coordinates**

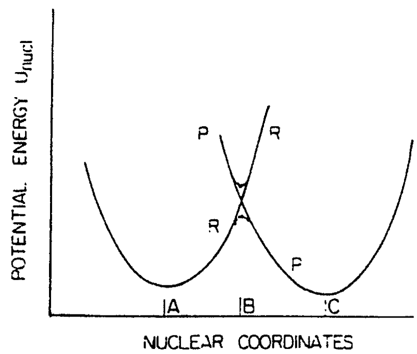
Ψ, χ**: electronic and ionic states, resp.**

***transition rate* (Fermi's Golden Rule)**

$$w_{fi} = \frac{2\pi}{\hbar} \, |H_{fi}|^2 \cdot FC \;;$$

FC **: Franck-Condon factor (Overlap integrals)**

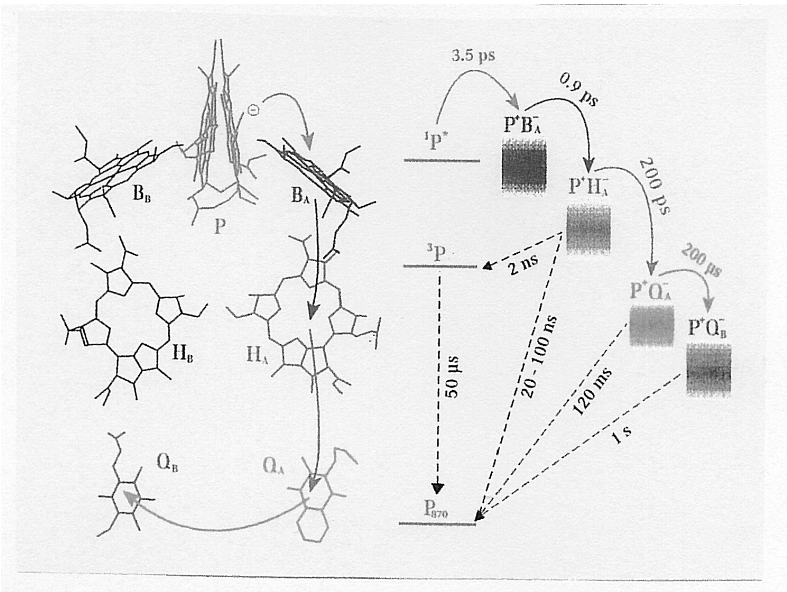




Quasiparticle picture:
electron tunneling potential

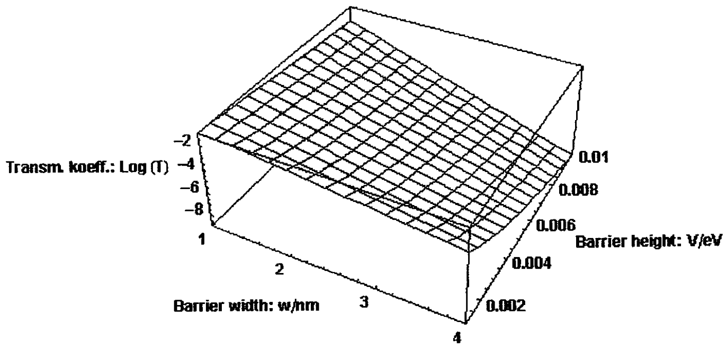
Numbers:

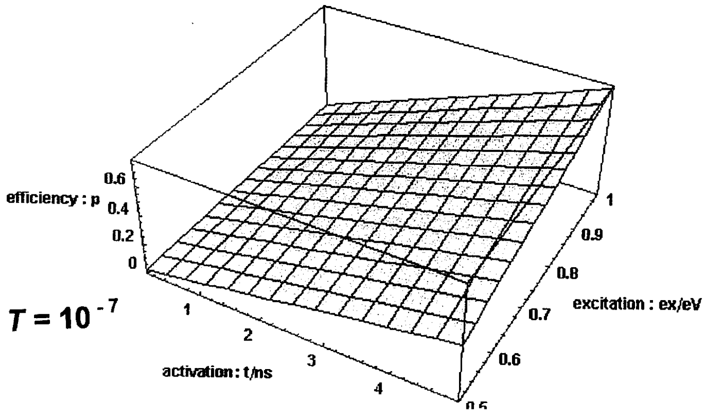
time scales* for *biological reaction center* (*Vos et al., 1993)



results for *tunneling model*

effective mass fixed: $m_{eff} = 5\ m_e$ (m_e electron mass)

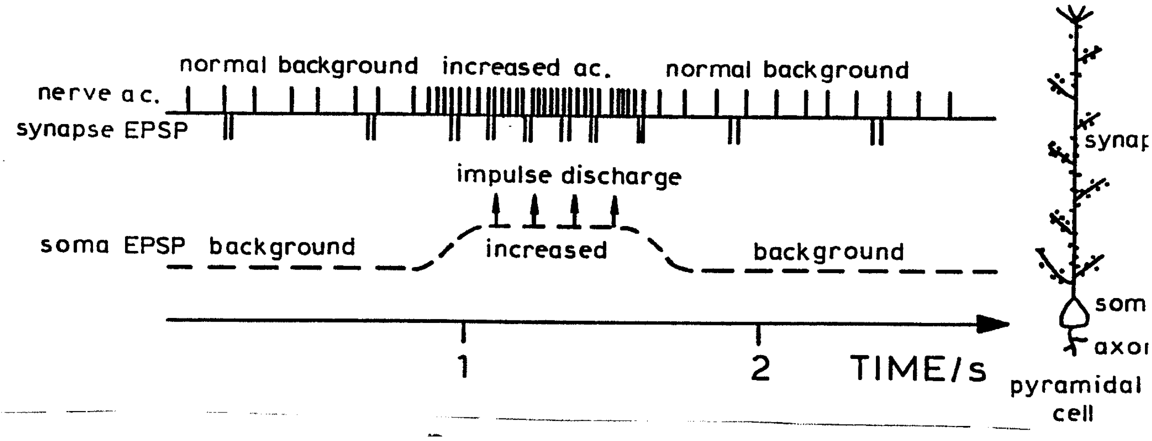




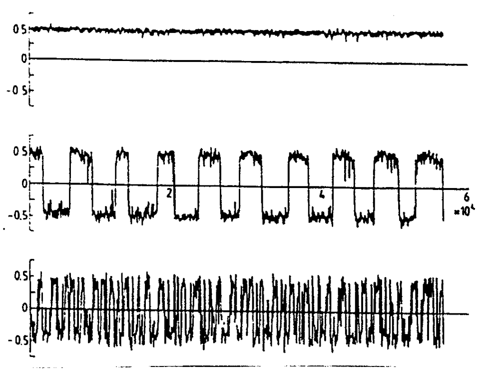
5. The Binding Problem: Spatio-temporal Coherence

Coherence **in the** ***neuronal net*** **:** ***self-organization*** **in** ***dendritic bundles*** **of** ***pyramidal cells*** **close to** ***instability*** **and under influence of** ***noise***

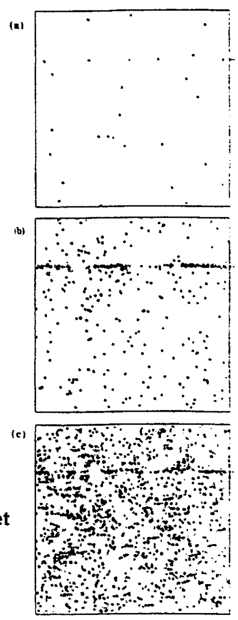
Spontaneous **neural firings**



Excycitable System **: synapses couple groups of neurons and generate** ***stable temporal structures*** **Hopfield-model)** ***amplified*** **by** ***stochastic resonace***



stochastic resonance in a bistable string
top to bottom: increasing noise level
(Benzi et al. 1985)



stochastic resonance in 2-D neural net
top to bottom: increasing noise
(Jung and Mayer-Kress 1995)

Long range coherence in biological systems

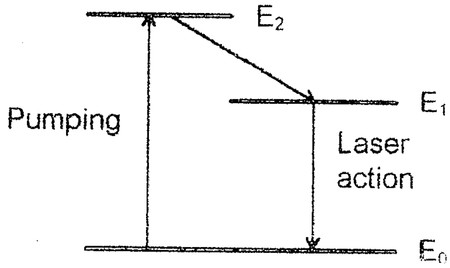
necessary ***ingredients:*** *dissipation* ***and*** *energy supply ("pumping")*

<u>pumping</u> ***$P(E_1) > P(E_0)$*** !

➔ <u>inversion</u>

"hotter than $T = \infty$ "

→ "negative" temperature



pumping *stabilizes* ***against thermal fluctuations***

phase synchronization ***of the laser action possible:*** <u>self organization</u>

<u>however:</u> *phase synchronization* ***mediated by*** *classical fields* ***(electromagnetic, molecular, ...)***

spectrum *quasi-continuous* ➔ <u>quantum state collapse not possible on this level</u>

Quantum state collapse* needs *few, well separated discrete states

***macroscopic quantum states* at *room temperature* :**

laser, Froehlich coherence

6. <u>Conclusions</u>

- ***Macro-* and *micro-structures* have *largely different time scales***

- ***Microstructure* : *quantum processes* possible on *electronic* level**

- **Neuronal net: *synapses* and *tubulin dimers* regulate couplings between neurons**

- ***Electron tunneling* can trigger conformal changes in *synaptic membrane* and/or *tubulin molecules*. This is in principal open to *experimental verification***

- ***Binding* : *coupling* of *micro-* and *macro-structures* via *quantum stochastic resonance***

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