Quantum Mechanics, Dissipation and Quantum Processors

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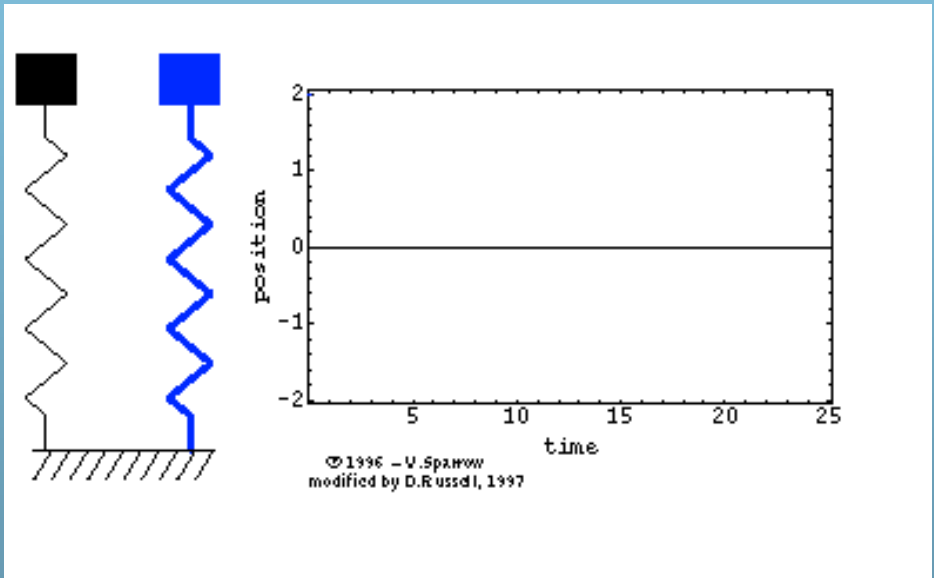
What is quantum dissipation?

dissipative motion

+

quantum mechanics

Dissipative motion

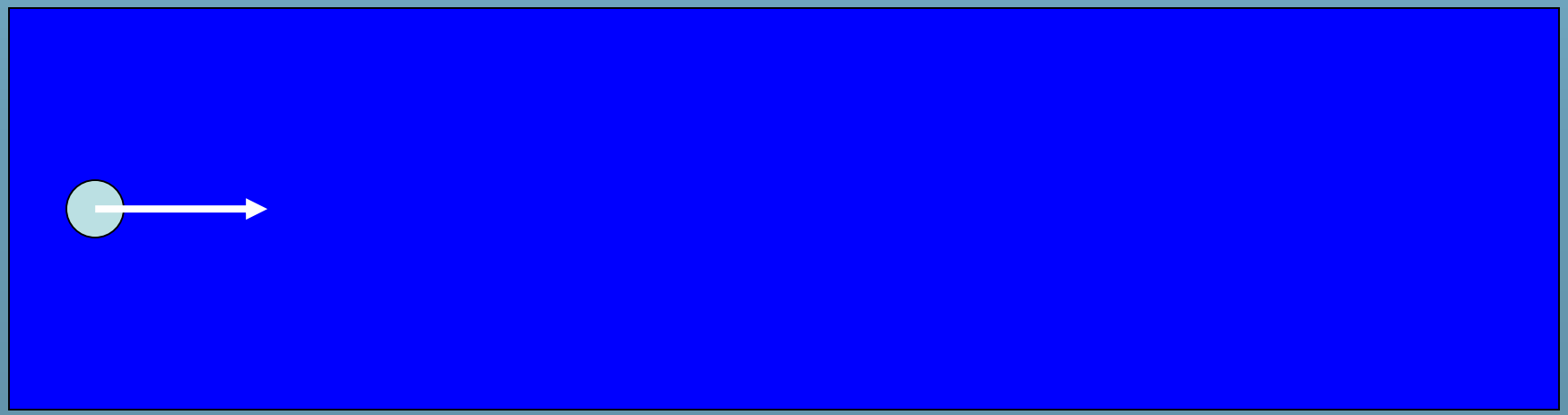


Dissipative motion

Motion is a viscous fluid

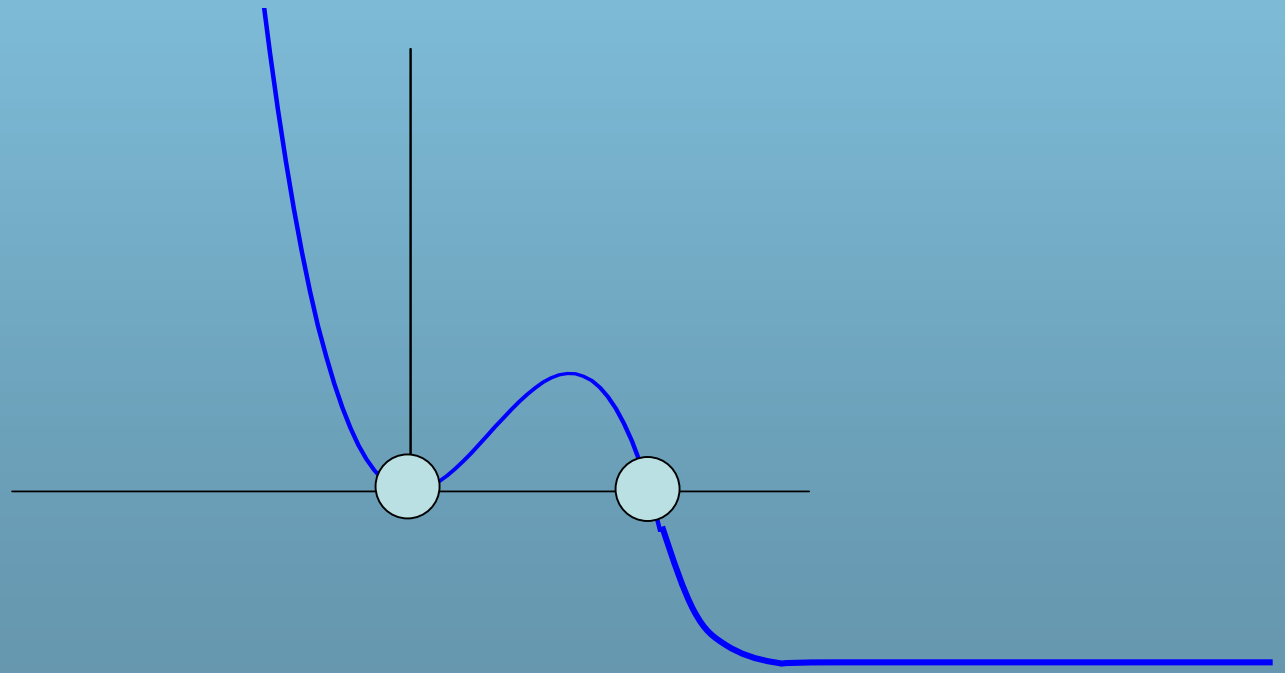
Dissipation + Fluctuations

Brownian motion



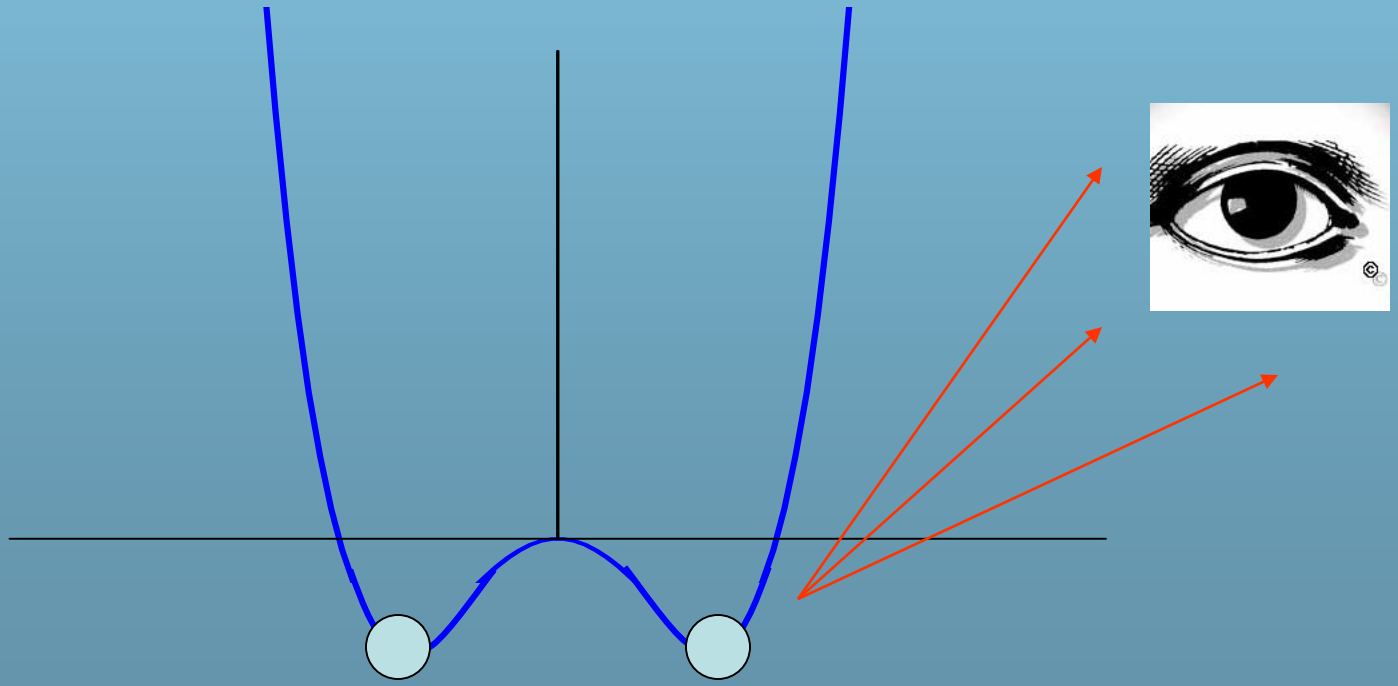
Quantum mechanics through simple examples

Tunnelling of a “quantum bead”



Quantum mechanics through simple examples

Coherent tunnelling of a “quantum bead”



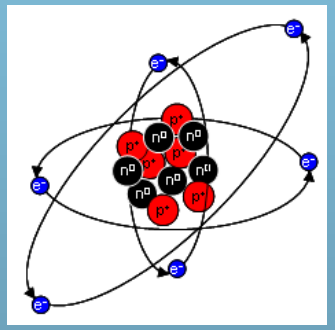
The main problem

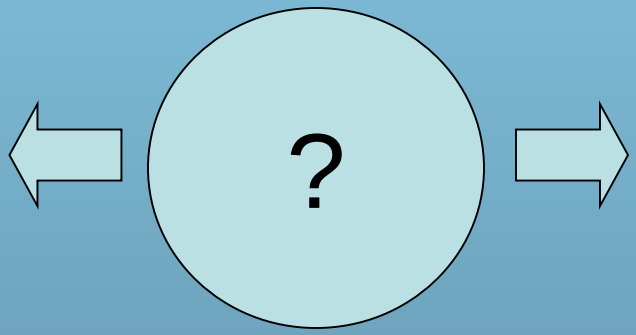
quantum mechanics x dissipation

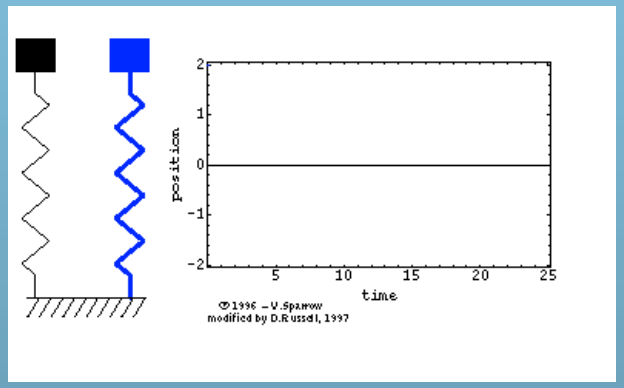
- Quantum mechanics applies to systems in the atomic or sub-atomic scales: isolated or controlled biased systems

- Dissipation occurs in macroscopic systems subject to the uncontrollable effects of the environment.

Where could both effects be simultaneously observed?







$10^{-9}\,m \le d \le 10^{-6}\,m$

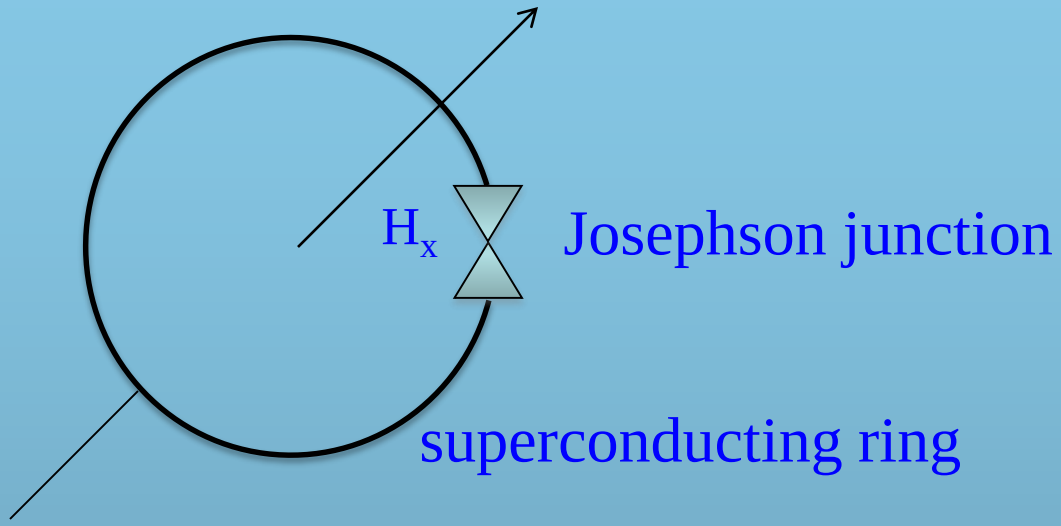
Quantum
(microscopic)

$d \le 10^{-9}\,m$

Classical
(macroscopic)

$d \ge 10^{-6}\,m$

The SQUID (superconducting quantum interference device): a paradigm



The equation of motion for the total flux

$$C\ddot{\phi} + \frac{1}{R}\dot{\phi} + \frac{dU}{d\phi} = 0 \quad \text{where}$$

$$U(\phi) = \frac{(\phi - \phi_x)^2}{2L} - \frac{i_c \phi_0}{2\pi}\cos\frac{2\pi\phi}{\phi_0}$$

C is the capacitance of the junction

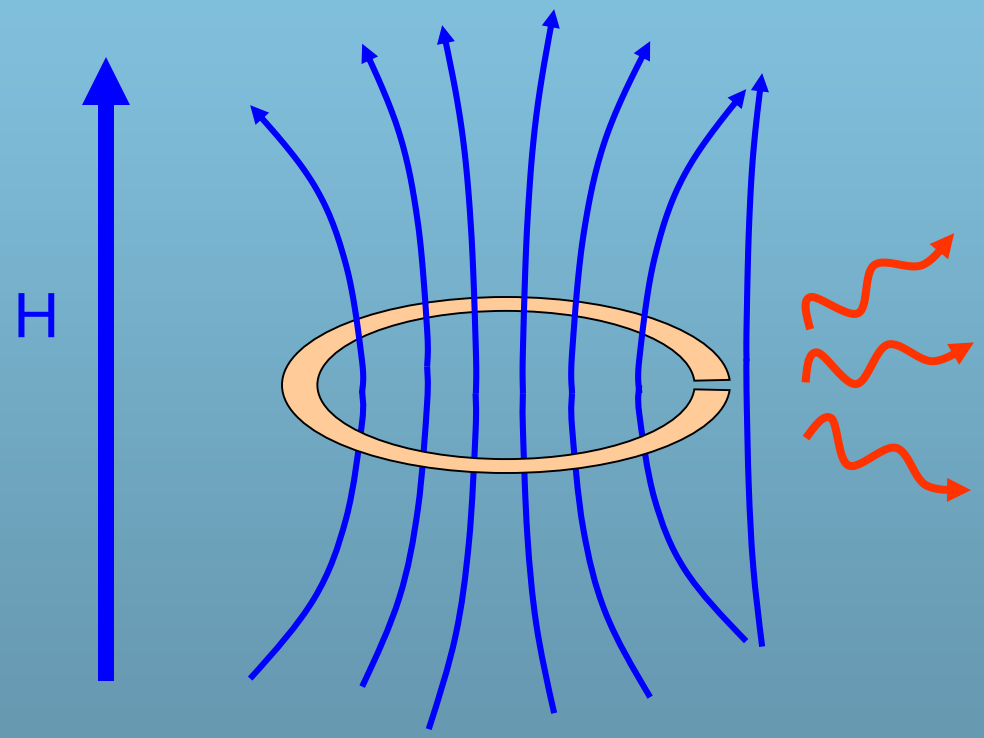
i_c is the critical current

R is the normal state resistance

ϕ_0 is the flux quantum

ϕ_x is the external flux (H_x x area)

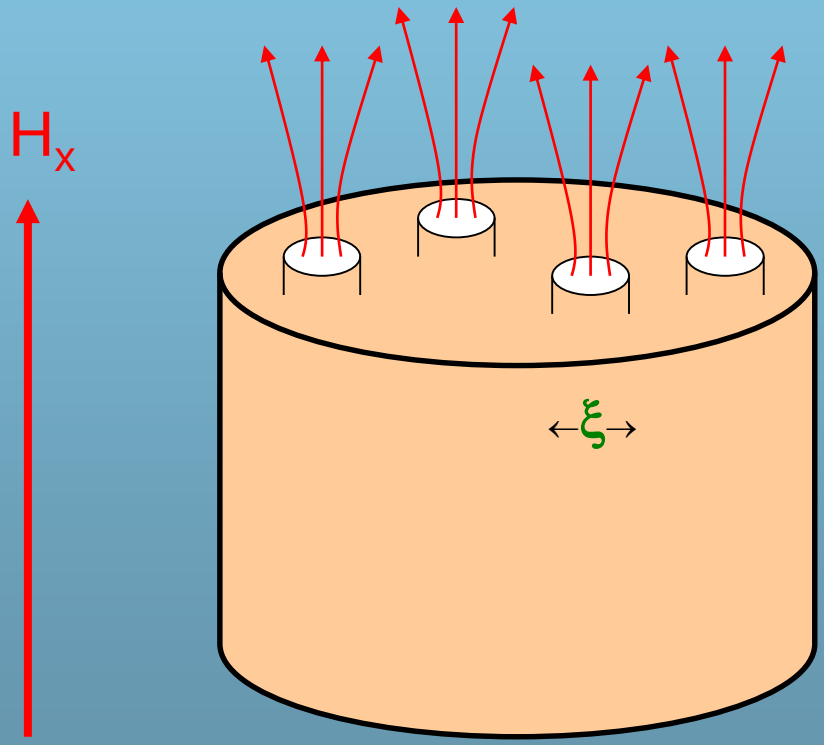
Fluxoid tunnelling

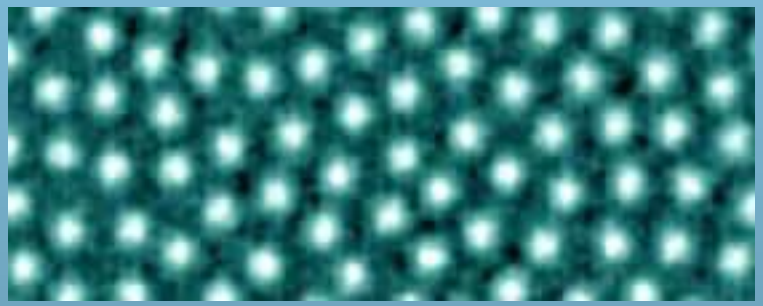


is what happens, but dissipation tends to destroy it !

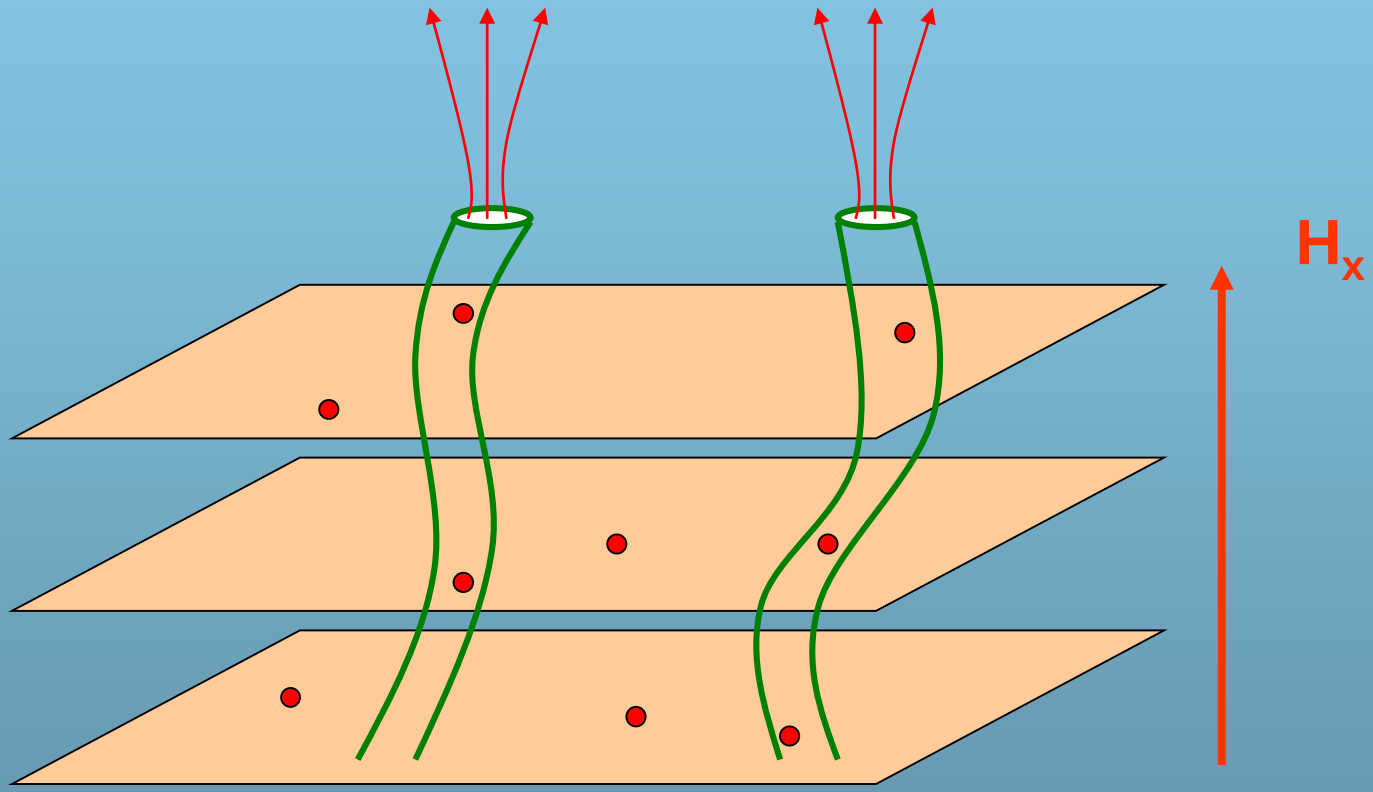
Vortices in superconductors

Type II superconductors

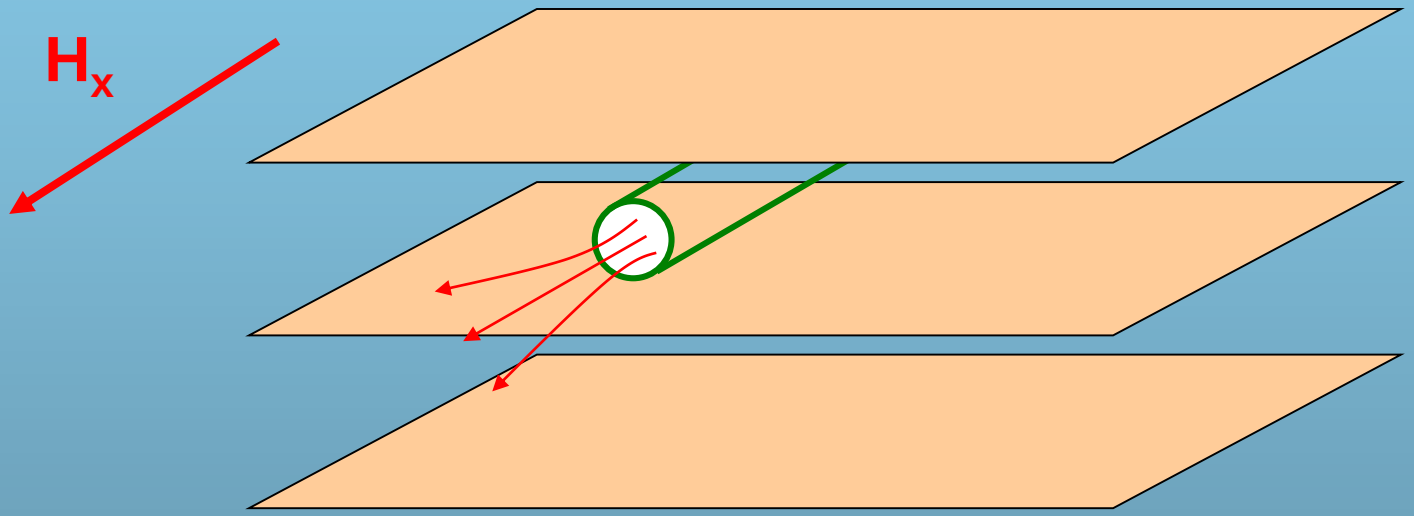




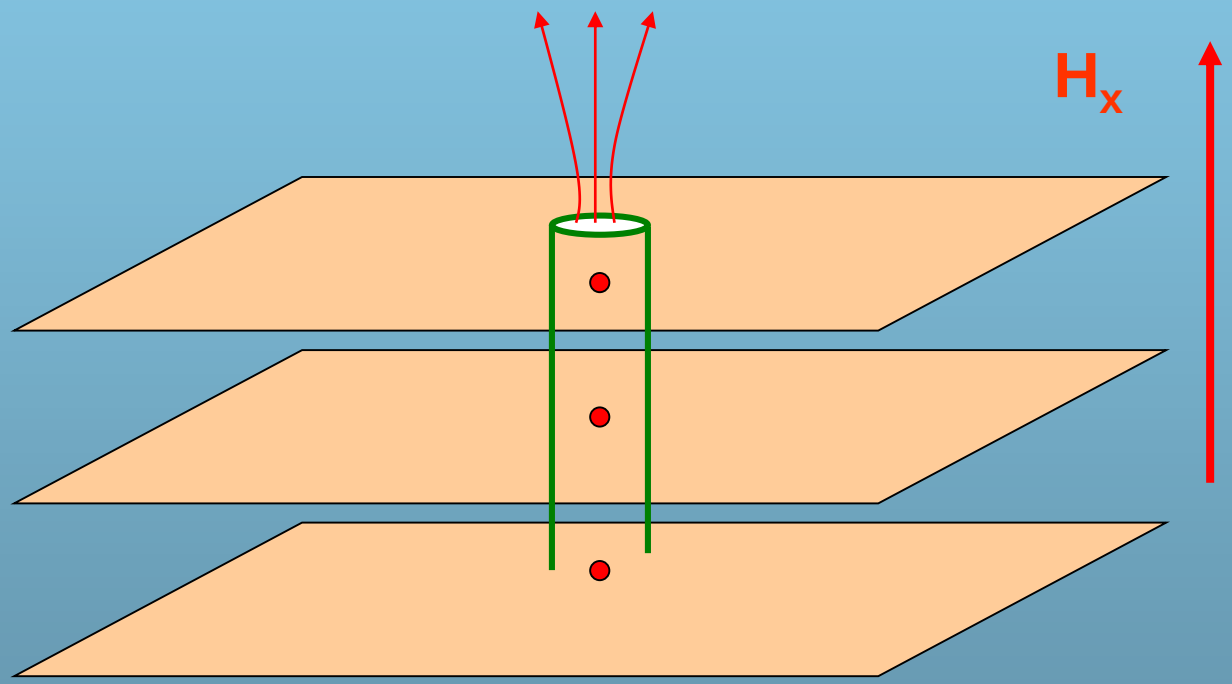
Vortices pinned by impurities



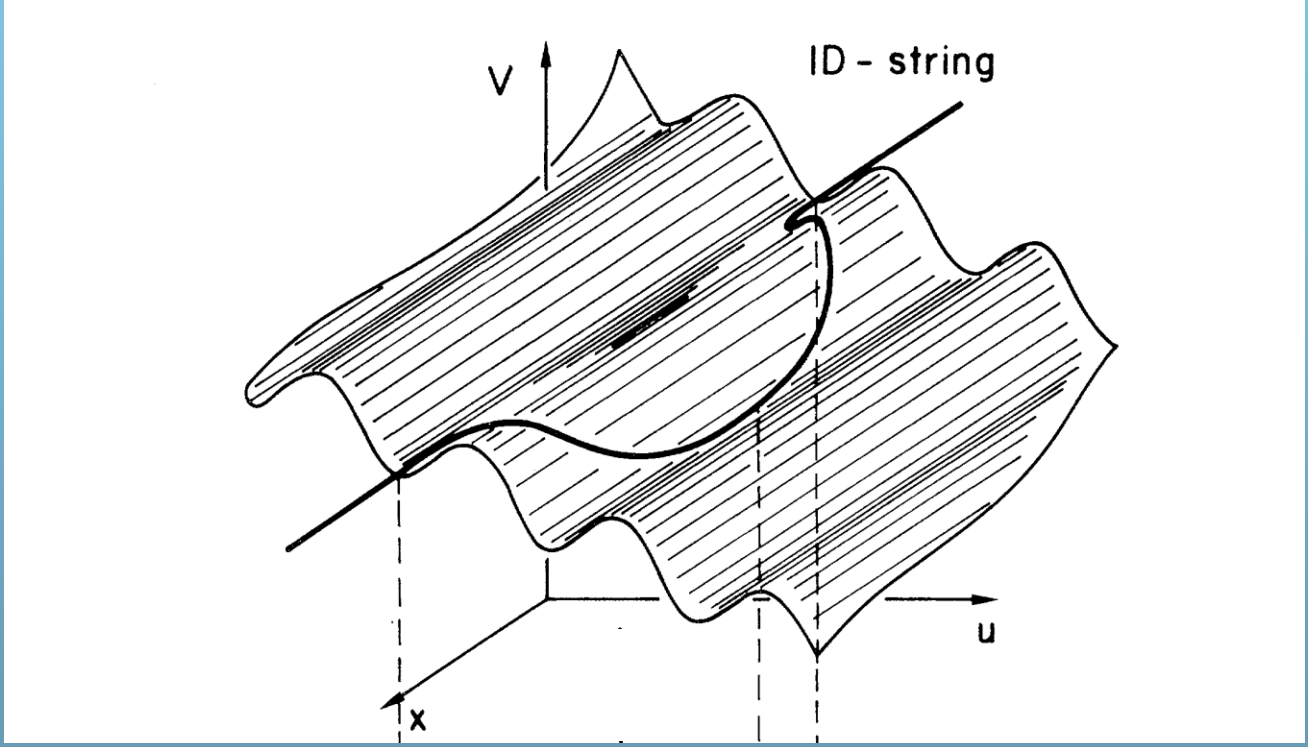
Intrinsically pinned vortices



Vortices pinned by columnar defects

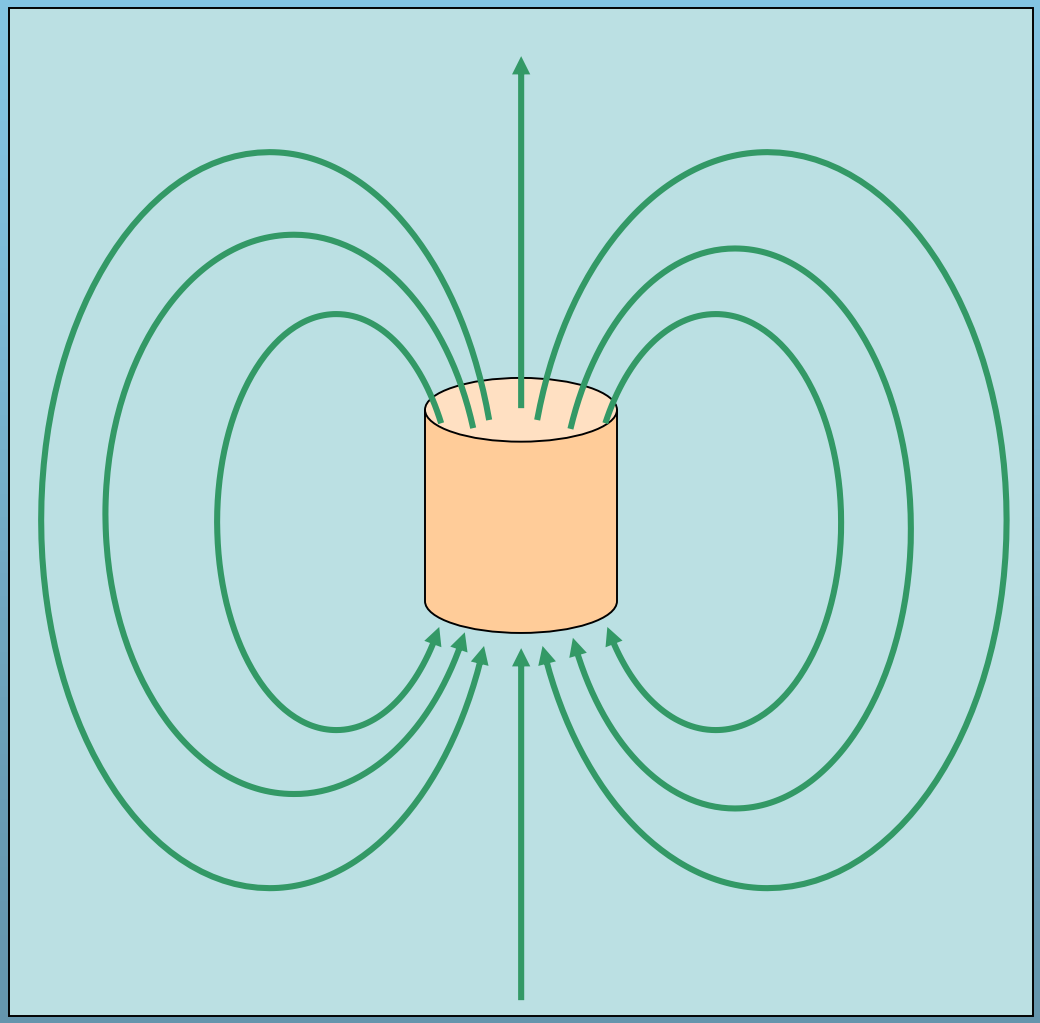


Equivalent mechanical problem



Dissipation tends to inhibit quantum effects !

Magnetic systems



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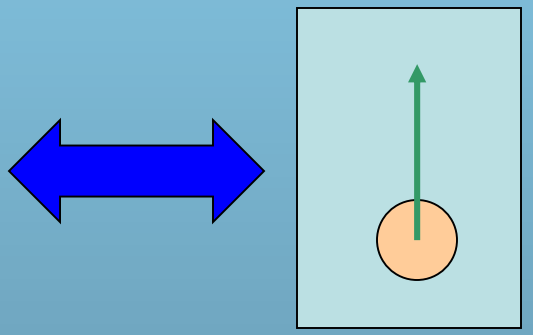
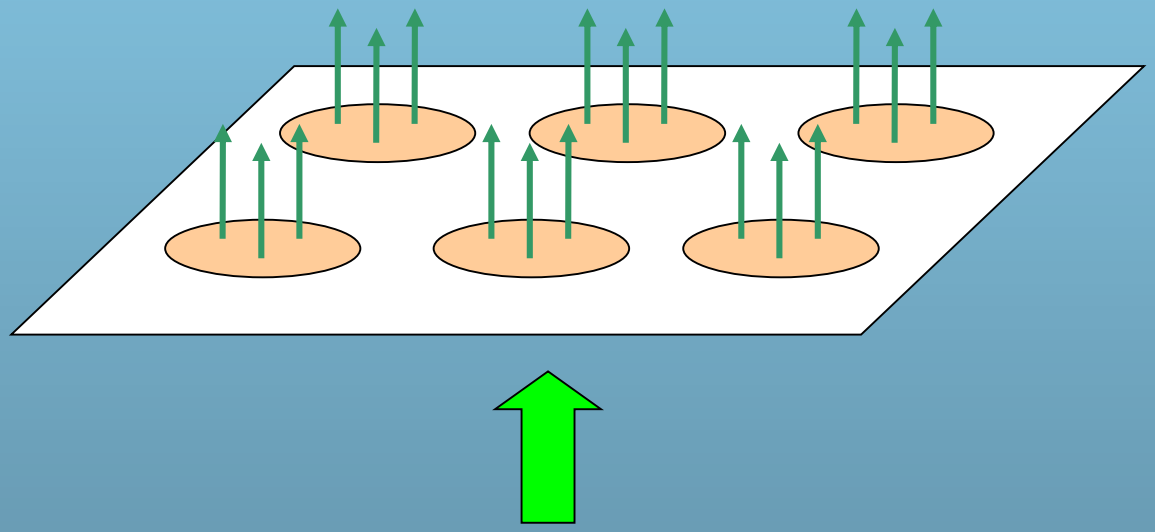


Magnetic
moment
(spin)

Magnetic systems

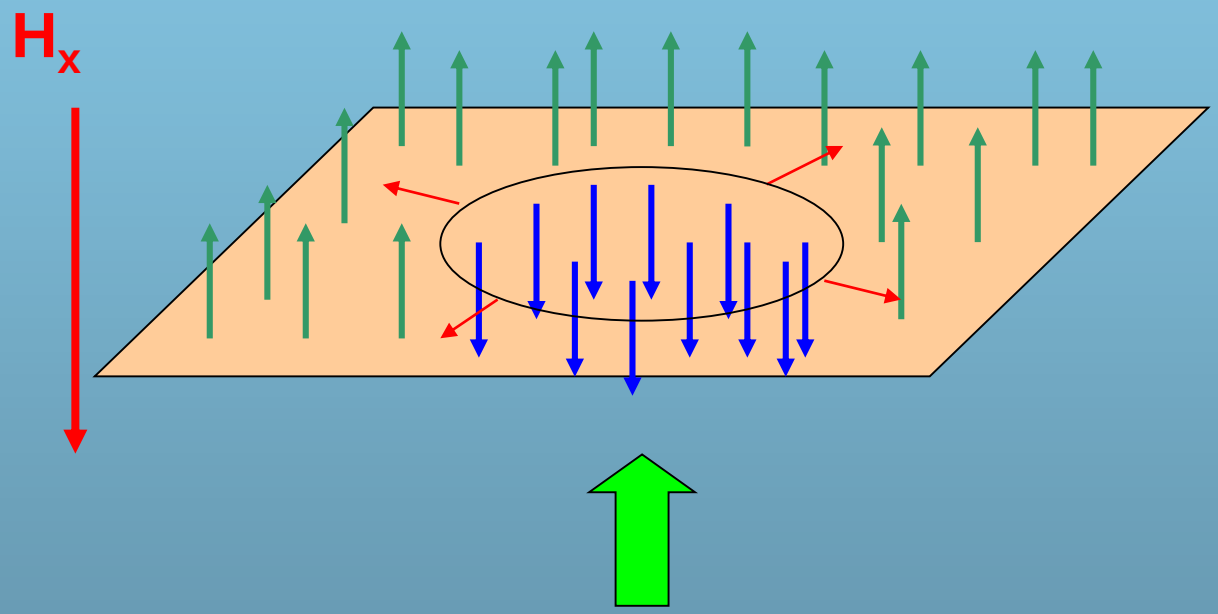
Magnetic particles



Coherent tunnelling of magnetic particles
($10^3 \longrightarrow 10^4$ spins per particle)

Magnetic systems

Quantum nucleation

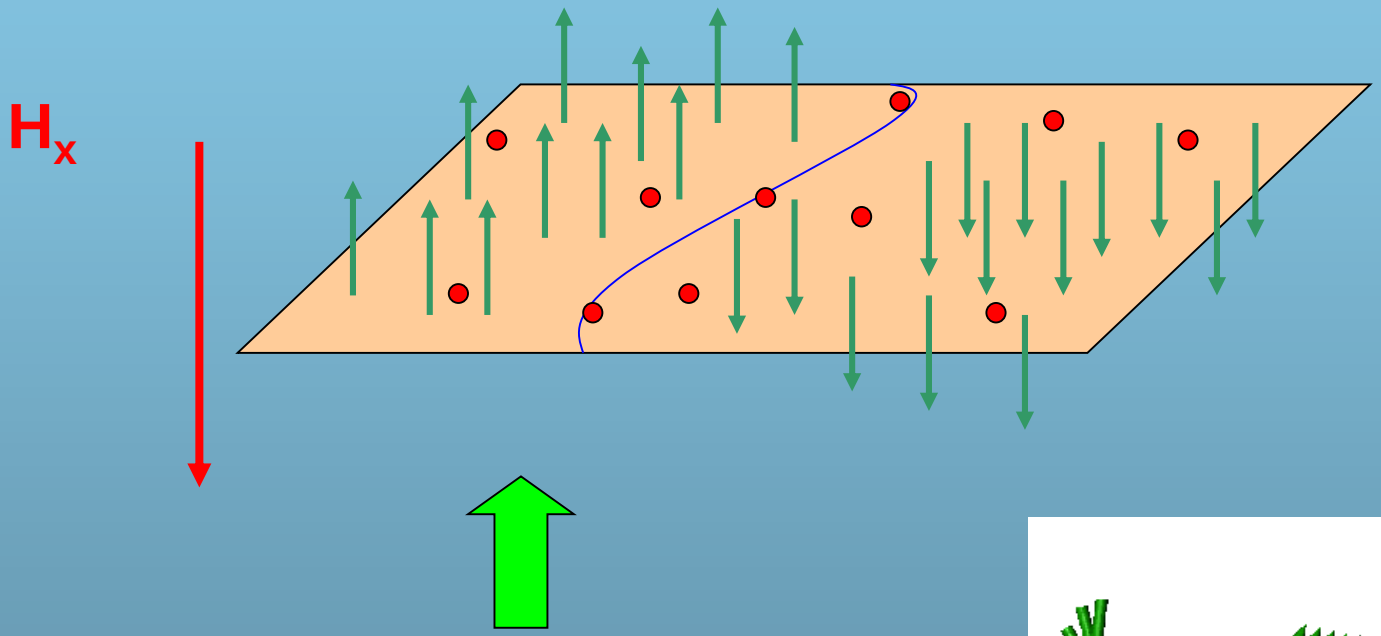


Quantum nucleation

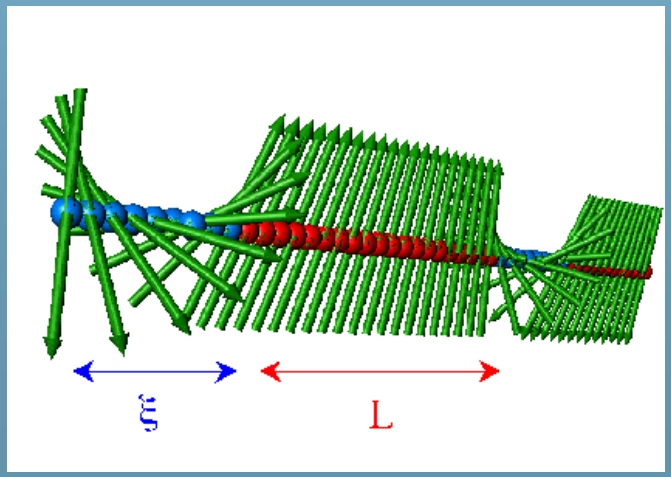
# of spins $\propto S_{\text{critical domain}} / S_{\text{sample}}$

Magnetic systems

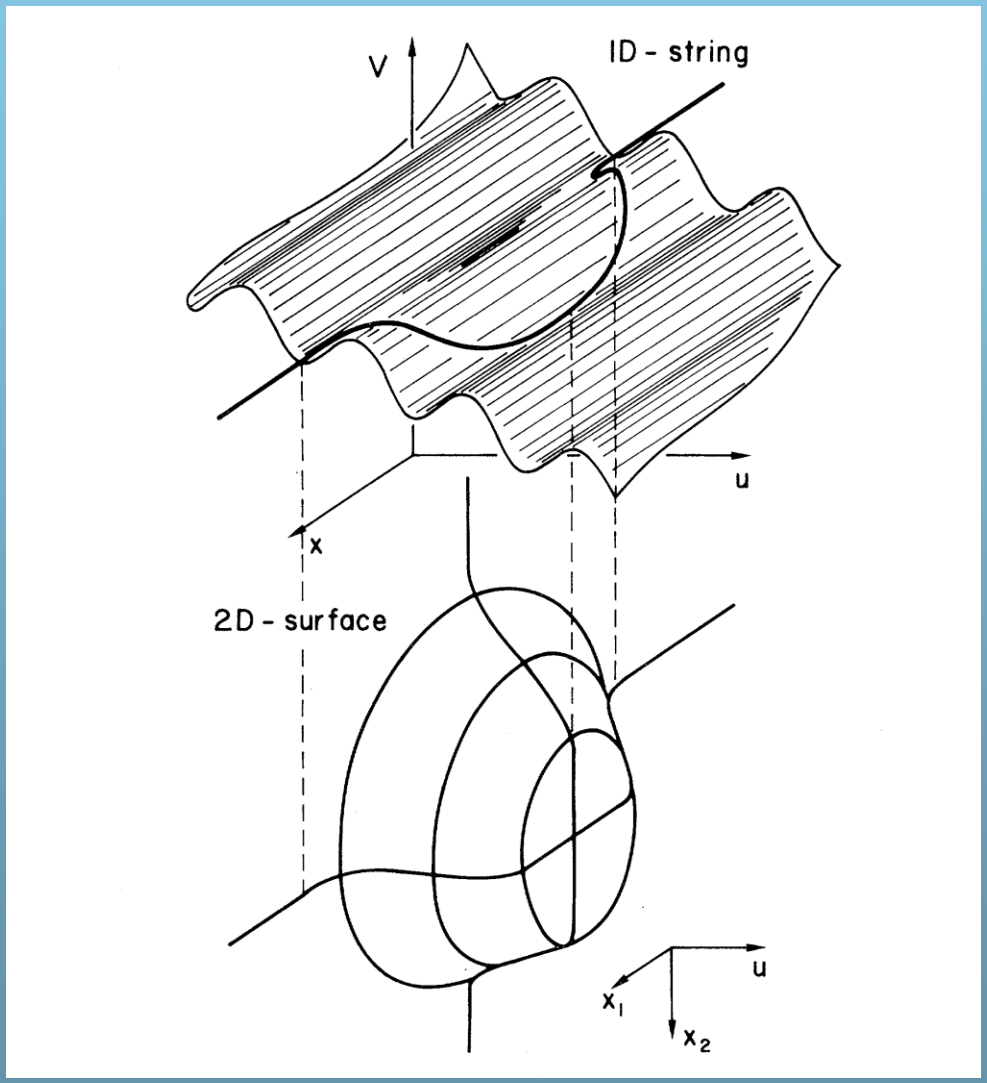
Domain wall tunnelling



Tunnelling of pinned domain walls



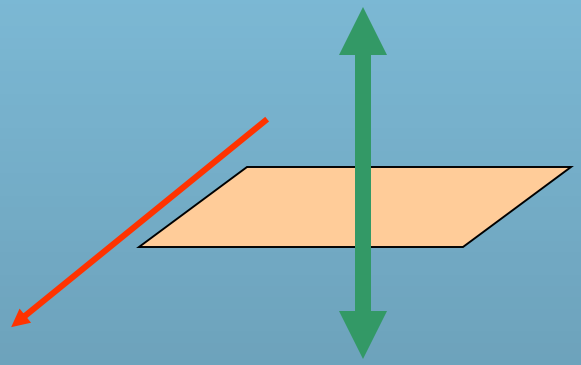
Equivalent mechanical problems

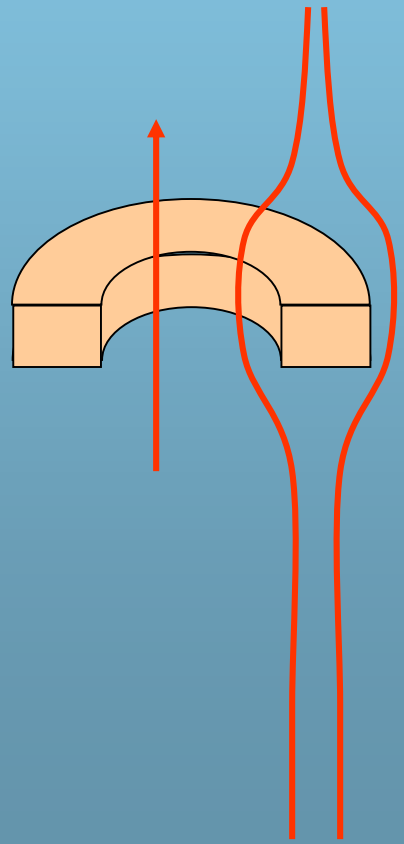


Dissipation tends to inhibit quantum effects !

Two-level systems

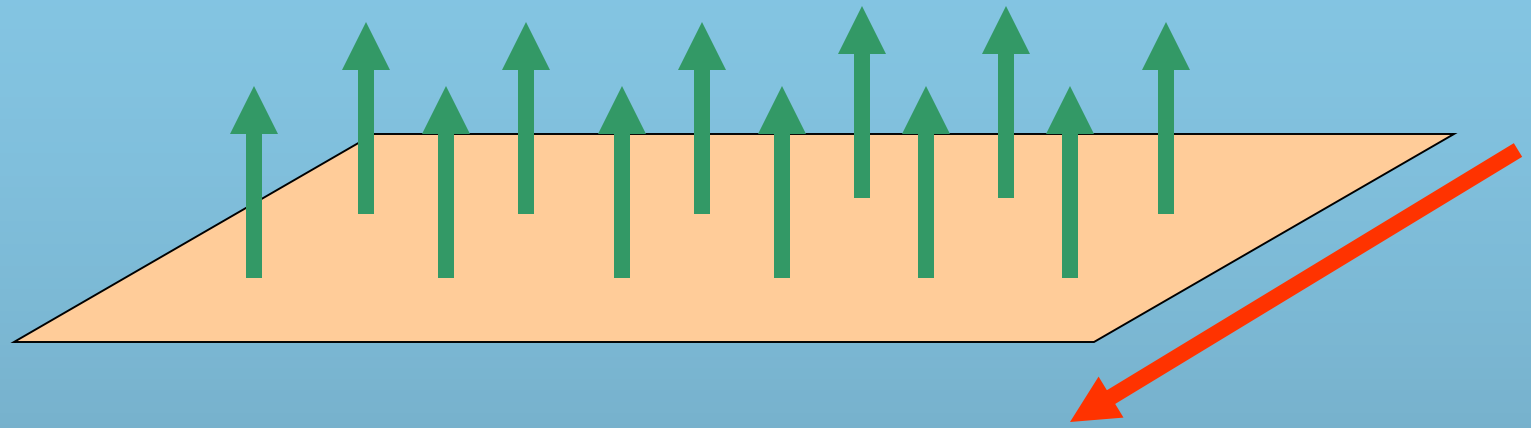
Various systems we have introduced involve superpositions of two configurations





$$|\psi\rangle = a|\uparrow\rangle + b|\downarrow\rangle$$

Devices and qubits



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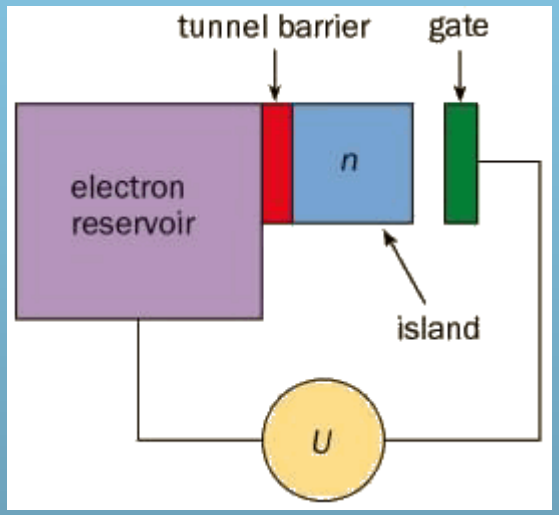
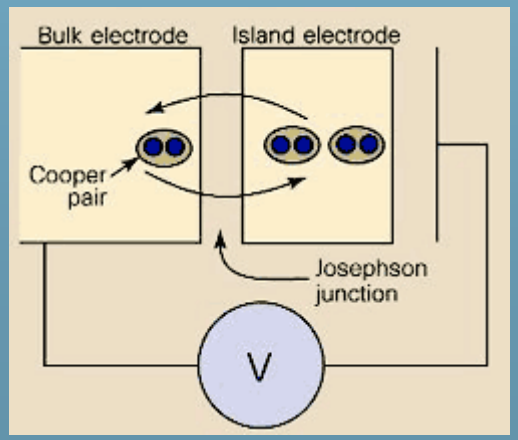
Dissipation destroys the coherence needed for the functioning of a quantum processor: decoherence!

The challenge is then to control dissipation

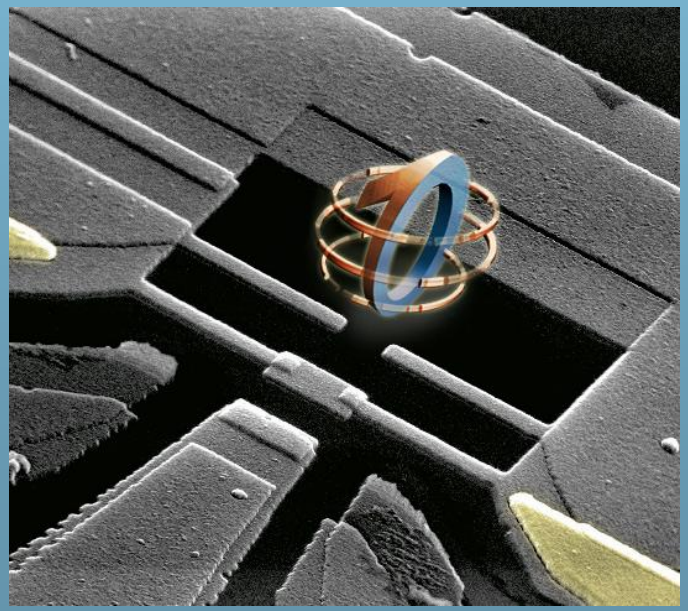
Some candidates for qubits

Superconducting devices: beside SQUIDs, which are flux qubits, and CBJJs, which are phase qubits, there are also charge qubits ; the Cooper pair boxes!



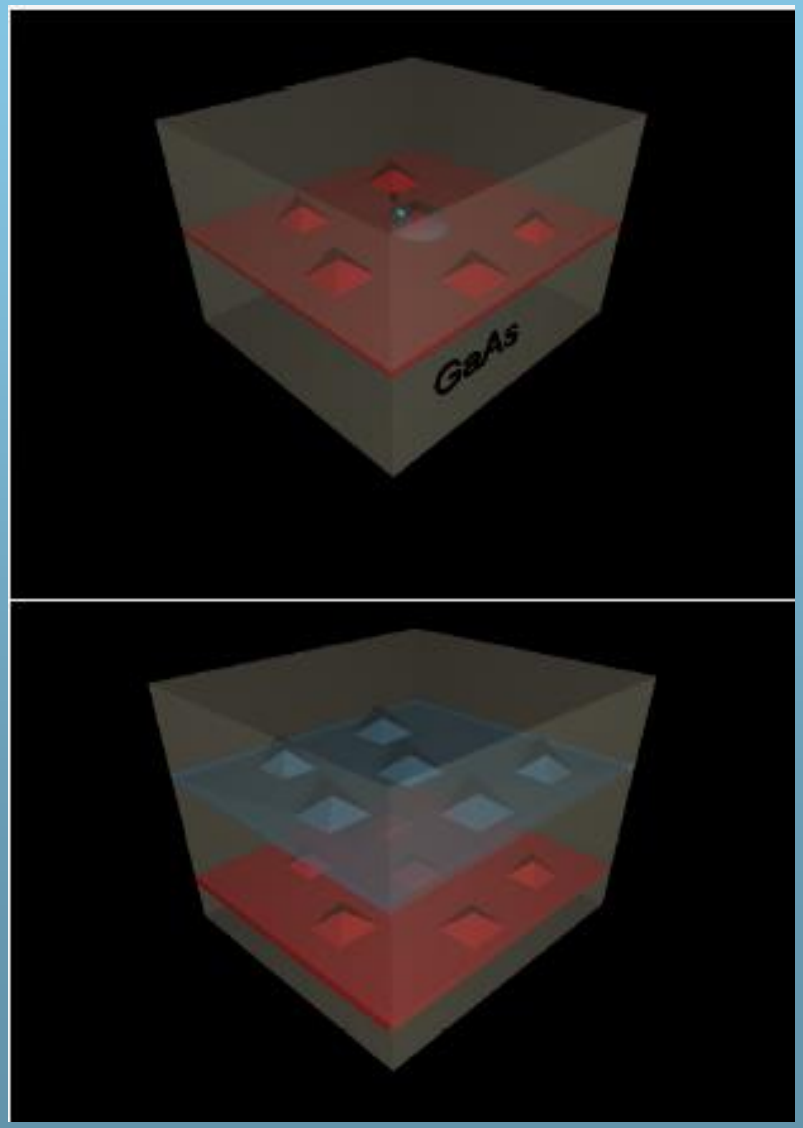


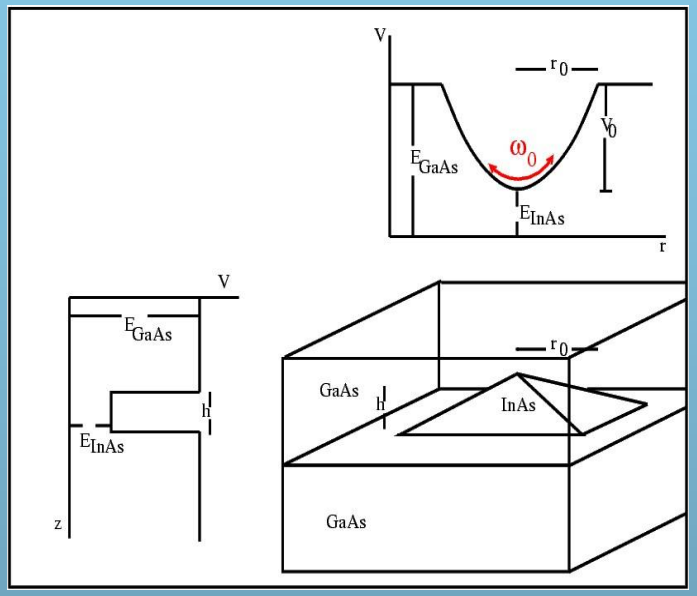
the quantronium

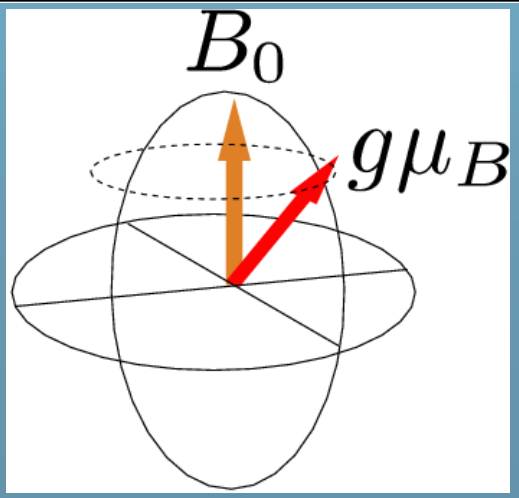


Some candidates for qubits

Electronic spin in quantum dots



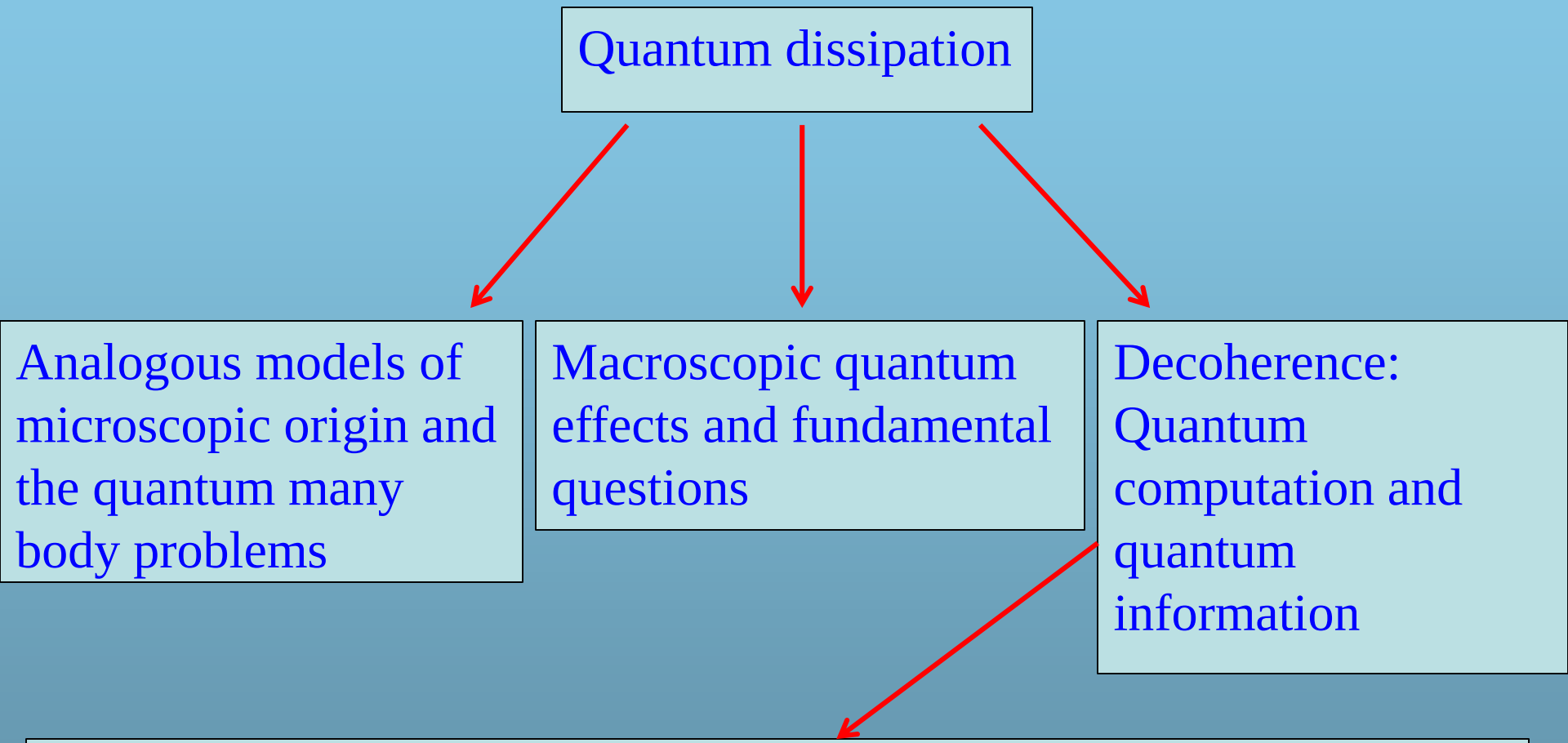




More candidates

- ions in linear traps
- photons in optical cavities
- fluxoids in superconducting devices
- NMR in molecules

Development of the area



Development in Brazil during the last decade: 2 Millenium Institutes (World Bank and CNPq) and the National Institute of Science and Technology for Quantum Information (CNPq-MCT and FAPESP).