
بسم الله الرحمن الرحیم

Violation of Leggett-Garg Inequality in a Two-Level System under decoherence

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- Macroscopic Quantum Phenomena (MQP)
- Examples of (MQP)
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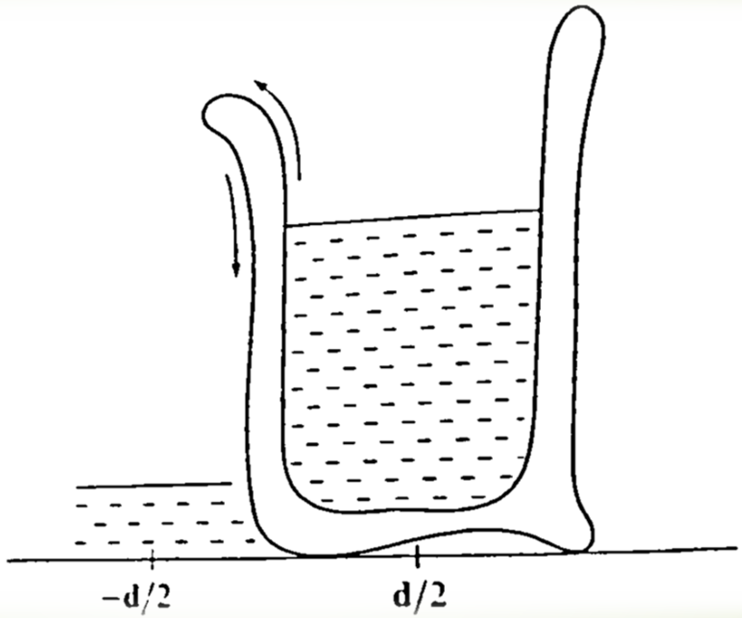
Macroscopic Quantum Phenomena

- Four Nobel prizes between 1996 to 2003
- Macroscopic means
  - → Systems with many components
  - → Size of the object

Examples of MQP

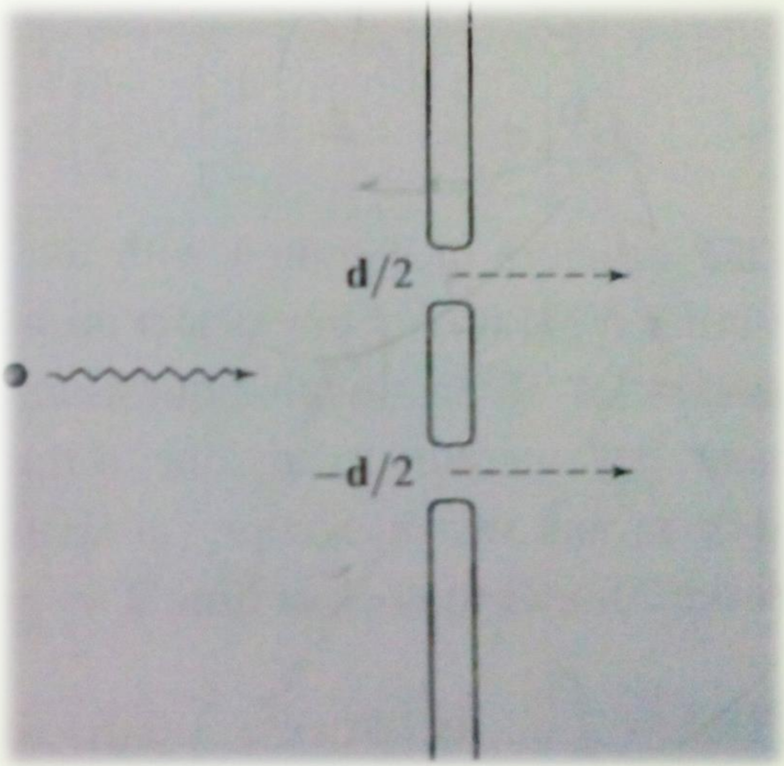
- Superconductivity
- Superfluidity
- SQUIDs
- Bose Einstein condensates
- Electro- and opto-mechanical devices
- C_{60} molecules interferences

Liquid ^{4}He



$$\prod_{k=1}^{N}\left\{\psi\left(r_k-\frac{d}{2}\right)+\psi(r_k+d/2)\right\}$$

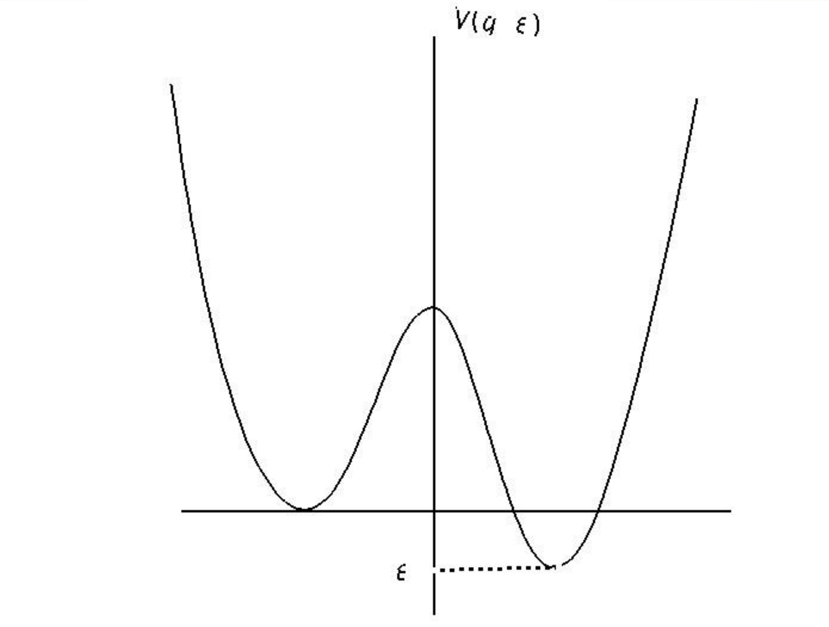
A ball passing through double slits



$$\prod_{k=1}^{N} \psi_K(r_k - d/2) + \prod_{k=1}^{N} \psi_k(r_k + d/2)$$

Tilted double-well potential

- A unique opportunity to study the fundamental behavior of a MQS
- describe some special phenomena like ammonia flipping



Leggett-Garg Inequalities

Inequalities to decide between macrorealism(MR) and quantum mechanics(QM)

They based on the following two assumptions

- MRA1: Macroscopic definiteness
- MRA2: Non-invasive measurability

Dimensionless equation

- Macroscopic is defined through dimensionless equations.
- A new parameter $\tilde{h}$ is defined which is a measure of macroscopic trait.

$$\tilde{h} = \frac{\hbar}{P_{\circ} U_{\circ}}$$

- h=0.1 is the quasi-classical situation.

Environmental effect

- We consider the effects of environment as a perturbation on the system.
- The environment assumed to be a bosonic field.
- The ground state of $H_\varepsilon$is |vac> and $|\alpha>= b^\dagger|vac>$is the state with a single boson . The state $|n, vac\rangle\rangle$ is an eigenstate of $H_0 = H_s + H_\varepsilon$ with energy E_n.
- $\delta E_n$is the related shift due to the perturbation of the interaction Hamiltonian.

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Obtaining Tunneling Probabilities

We suppose that the macrosystem is initially in the left well, after time t we calculate the probability of finding it in the right well

$$sin^2\theta + (sin^2\theta cos2\theta)e^{-\Gamma_1 t} - 2sin^2\theta cos^2\theta \cos(\Omega_{10}t)e^{-\Gamma_1 t/2}$$

Where θ depends on tilt and the energy splitting of two levels.

Γ_n^{-1} is the life time of the shifted energy.

$$sin^2\theta + (sin^2\theta cos2\theta)e^{-\Gamma_1 t} - 2sin^2\theta cos^2\theta \cos(\Omega_{10}t)e^{-\Gamma_1 t/2}$$

- $\cos(\Omega_{10}t)$ is evidence of MQC
- The decay term $e^{-\Gamma_1 t/2}$ reduces the strength of oscillation
- We work in principal time domain where $\Gamma_1 t \ll 1$

Violation of Leggett-Garg Inequality

- We calculated other tunneling probabilities
- We calculated time correlation functions
- Then we use the following inequality

$$\left|C_{32} - C_{31}\right| + C_{21} \leq 1$$

- For $0.5 \leq z \leq 1$ the inequality will be violated.
- $z = e^{-\gamma\tau}$ contains decoherence effects.

Conclusion

- A broader range of violation is obtained.
- Violation means the inaccuracy of macrorealism assumption.
- The noninvasive measurement is more likely to be inaccurate.
- For triple well potential our calculation show no violation.

References

- S. Takagi, Macroscopic Quantum Tunneling, Cambridge university press, New York (2005).
- C. Emary, N. Lambert, F. Nori, Rep. Prog. Phys. 77, 016001 (2014).
- M. Arndt, O. Nairz, J.V. Andreae, C. Keler, G.V.D. Zouw and A. Zeilinger, Nature 401, 680 (1999).
- Y. P. Huang and M. G. Moore, Phys. Rev. A 73, 023606 (2006).

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