

# Quantum observations talk 1

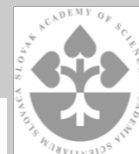
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## Thanks to:

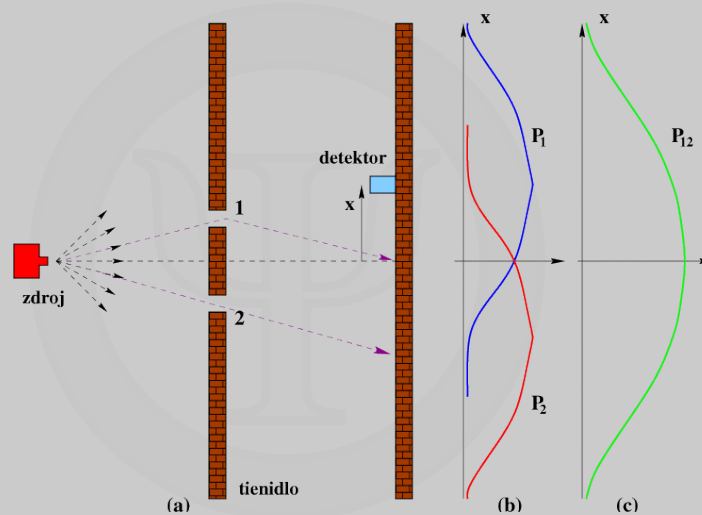


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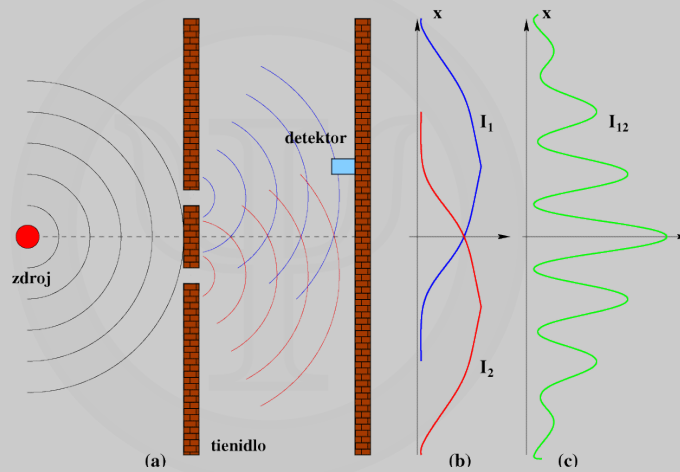
## Quantum interference

- Quantum superpositions
- Quantum entanglement
- Quantum interference
- Atom-field interactions
- Jaynes-Cummings model
- Exponential decay of two level atom
- What do we observe?

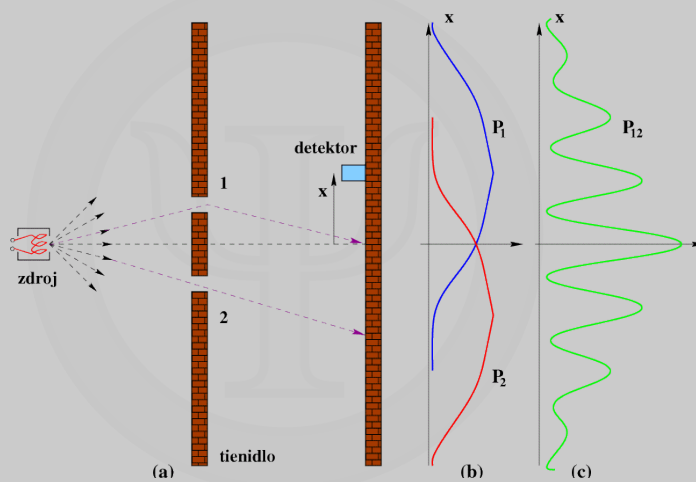
## Classical double-slit experiment I



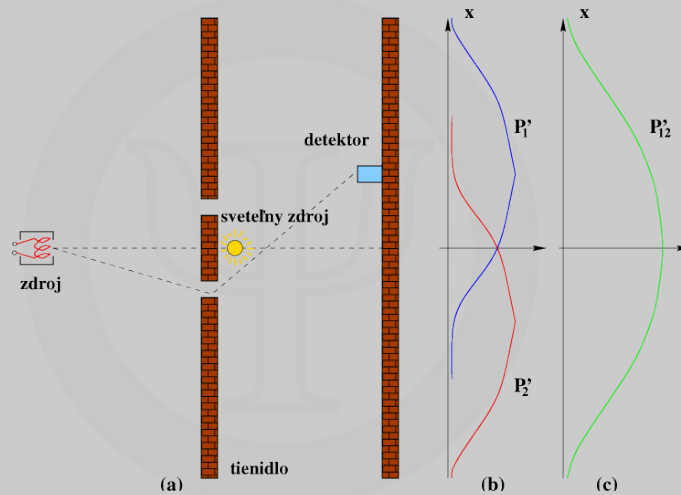
## Classical double-slit experiment II



## Quantum double-slit experiment I



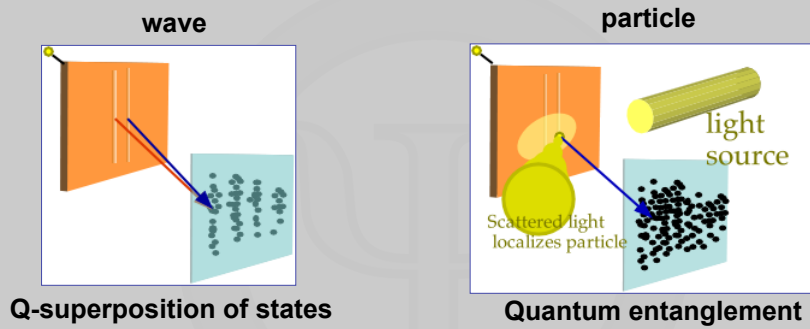
## Quantum double-slit experiment II



## Quantum system

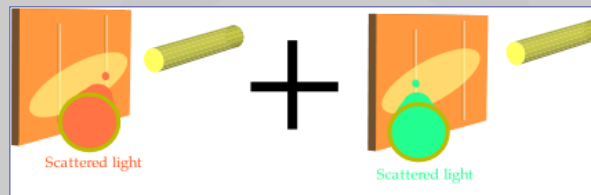
- The answer you receive very much depends on the question you ask
- Intrinsic uncertainty
- Statistical character of the theory
- „Collaps“ of the state during/after the measurement – the world is changing when we observe it

## Quantum interference & dualism

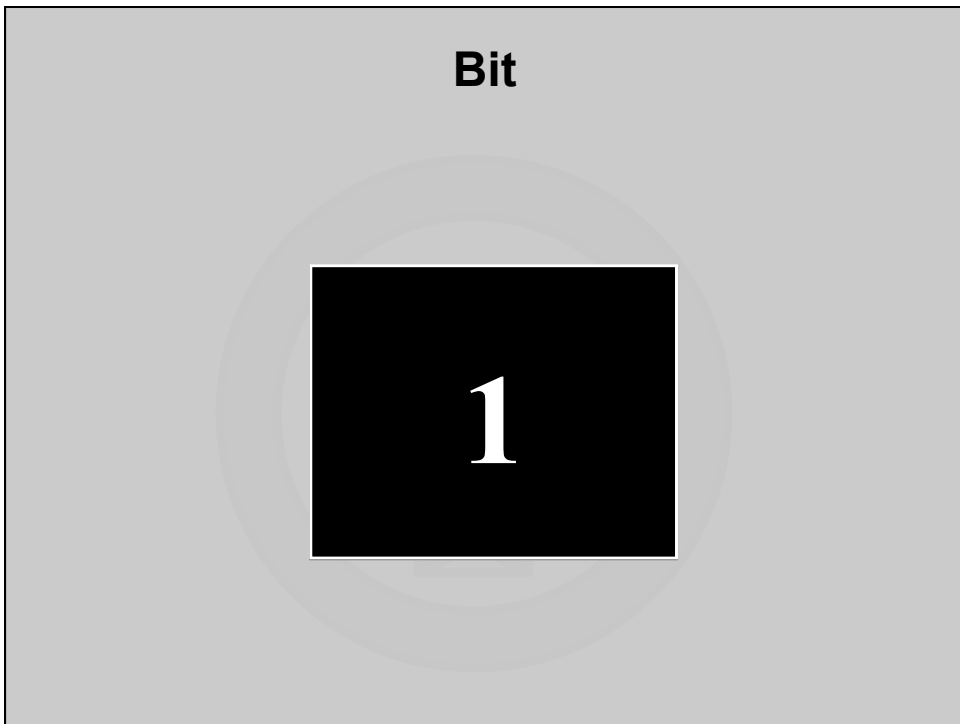
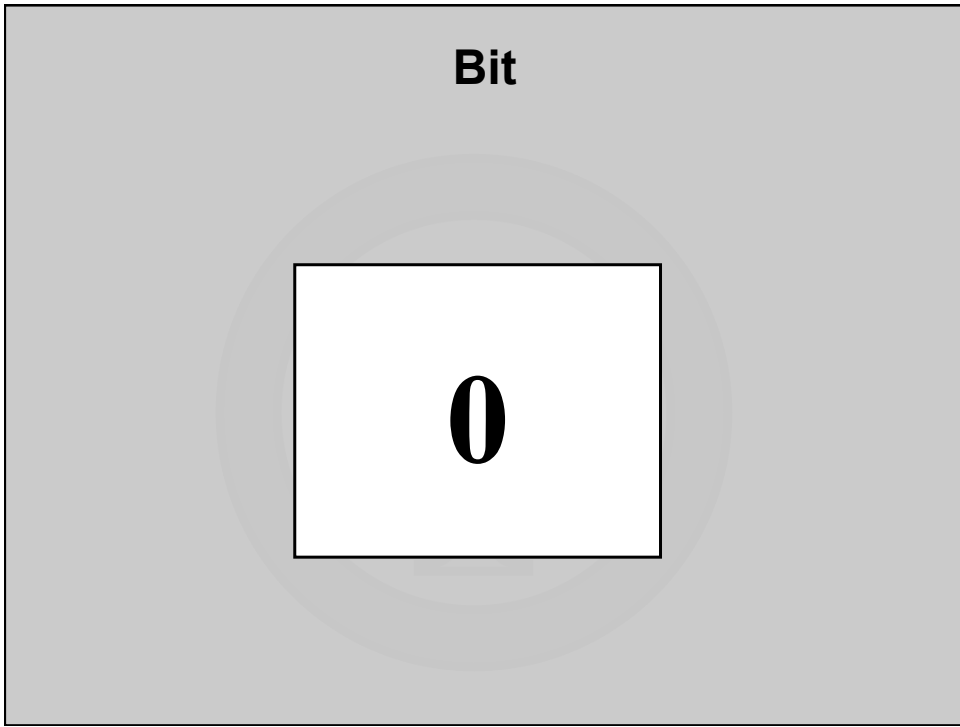


Quantum objects sometime behave like waves, sometime like particles. Their „behaviour“ depends on how we measure them.

## Quantum entanglement



Reflected photons are entangled with quantum systems – photons carry information about the slit via which the quantum systems flee through the screen. When the reflected photon is registered, the quantum coherence is disturbed and the interference pattern disappears.



## Quantum superposition: Qubit

Superposition of basis vectors

$$|\psi\rangle = \alpha|0\rangle + \beta e^{i\varphi}|1\rangle$$

Amplitudes of probability

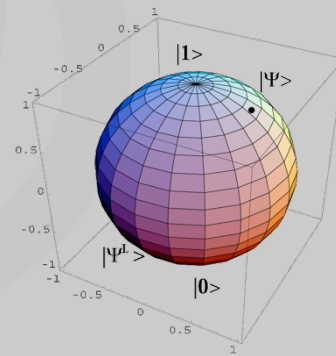
$$\alpha, \beta e^{i\varphi}$$

Probability

$$P_0 = |\alpha|^2$$

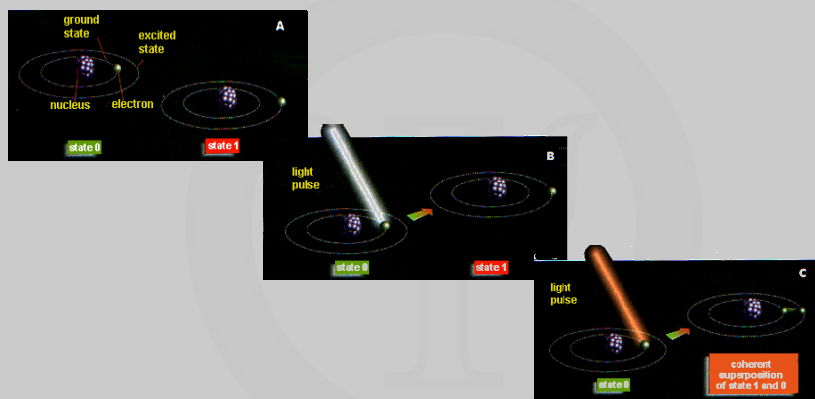
$$P_1 = |\beta|^2$$

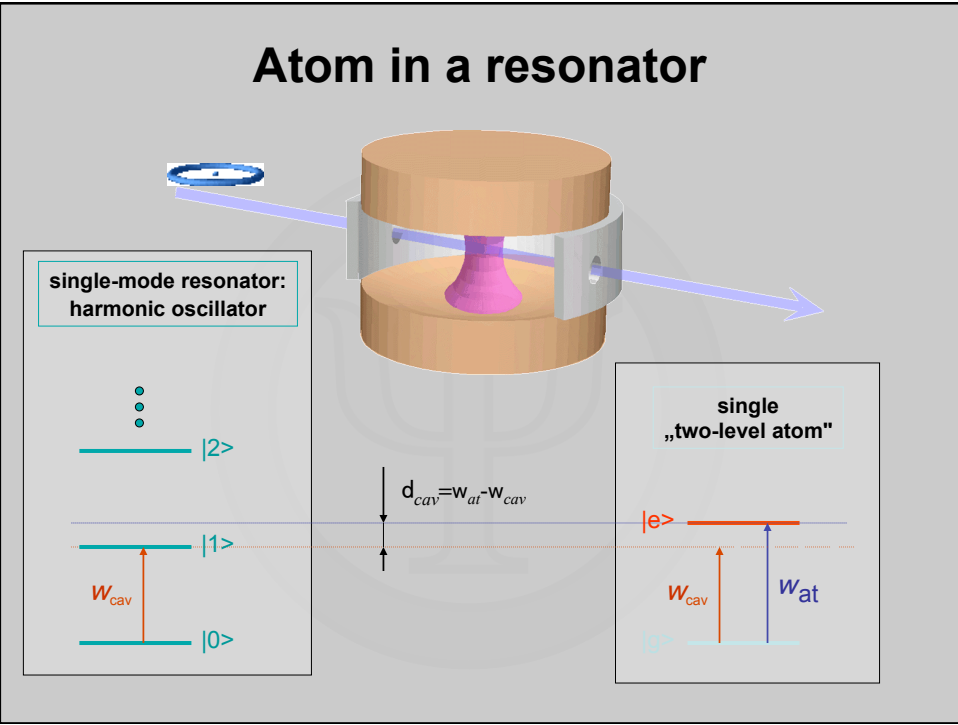
$$P_0 + P_1 = 1$$



Poincare sphere – state space

## Physical implementation: 2-level atom





### Jaynes-Cummings model

$$\sum_j \left( \begin{array}{c} \text{green} \\ |j\rangle \\ \text{red} \end{array} + \begin{array}{c} \text{red} \\ |j\rangle \\ \text{green} \end{array} \right)$$

$$H = \frac{\hbar\omega_A}{2} \sigma^z + \hbar\omega_F a^\dagger a + \hbar\kappa (a^\dagger \sigma^- + a \sigma^+)$$

**Initial state.**

$$i\hbar \frac{\partial |\Psi(t)\rangle}{\partial t} = H |\Psi(t)\rangle$$

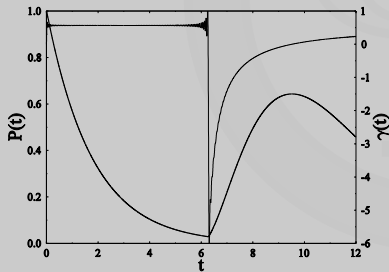
$$|\psi\rangle_{A-F} = c(t) |1\rangle |g\rangle + d(t) |0\rangle |e\rangle$$



## Decay of a two-level atom

$$H = \frac{\hbar\omega_A}{2} \sigma^z + \hbar\omega_F \sum_j a_j^\dagger a_j + \hbar\kappa \sum_{j=1}^N (a_j^\dagger \sigma^- + a_j \sigma^+) \quad \sum_j \left( \begin{array}{c} \text{green line} \\ \text{red line} \end{array} \right)$$

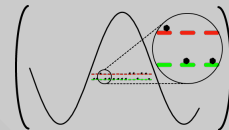
$$|\psi\rangle_{A-F} = \sum_{n=1}^N c_n(t) |0\rangle^{\otimes(N-1)} |1\rangle_n |g\rangle + d(t) |0\rangle^{\otimes N} |e\rangle$$



$$i\hbar \frac{\partial |\Psi(t)\rangle}{\partial t} = H |\Psi(t)\rangle$$

$$\frac{\partial \rho}{\partial t} = \frac{\gamma(t)}{2} (2\sigma_- \rho \sigma_+ - \sigma_+ \sigma_- \rho - \rho \sigma_+ \sigma_-)$$

## No tricks just quantum interferences



**Hamiltonian**

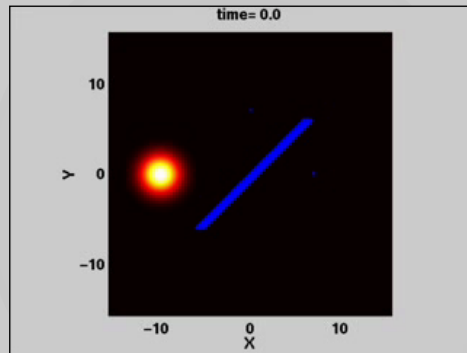
$$H = \frac{\hbar\omega_A}{2} \sum_{k=1}^M \sigma_k^z + \hbar \sum_{j=1}^N \omega_j a_j^\dagger a_j + \hbar \sum_{k=1}^M \sum_{j=1}^N \kappa_k (a_j^\dagger \sigma_k^- + a_j \sigma_k^+)$$

$$|\psi\rangle_{atom} = |g\rangle^{\otimes M}$$

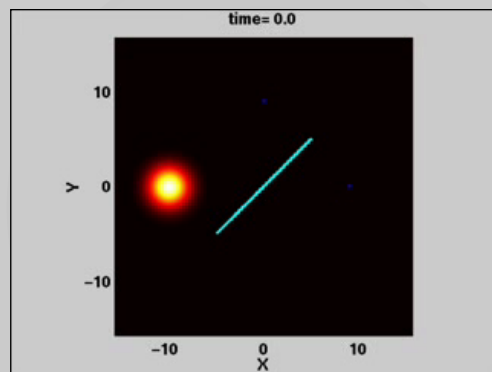
$$|\psi\rangle_{field} = \sum_{n=1}^N c_n |0\rangle_1 |0\rangle_2 \dots |1\rangle_n \dots |0\rangle_{N-1} |0\rangle_N$$

$$|\psi\rangle_{A-F} = \sum_{n=1}^N c_n(t) |0\rangle^{\otimes(N-1)} |1\rangle_n |g\rangle^{\otimes M} + \sum_{k=1}^M d_k(t) |g\rangle^{\otimes(M-1)} |e\rangle_k |0\rangle^{\otimes N}$$

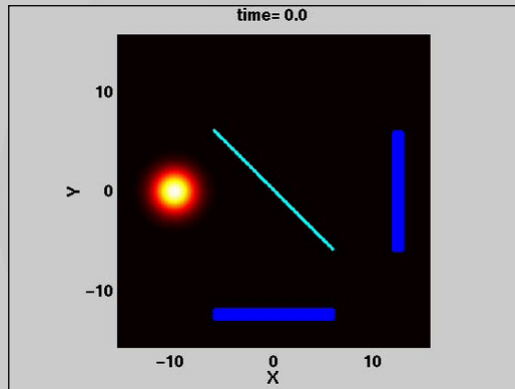
## Microscopic model of a mirror



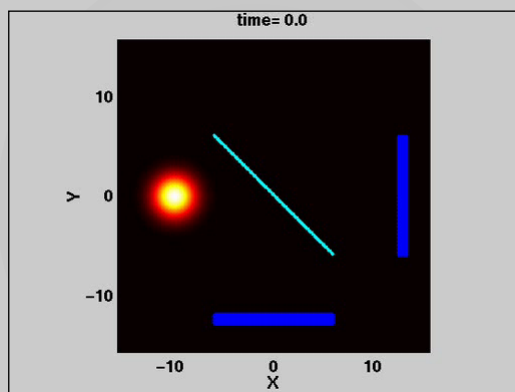
## Microscopic model of a beam-splitter



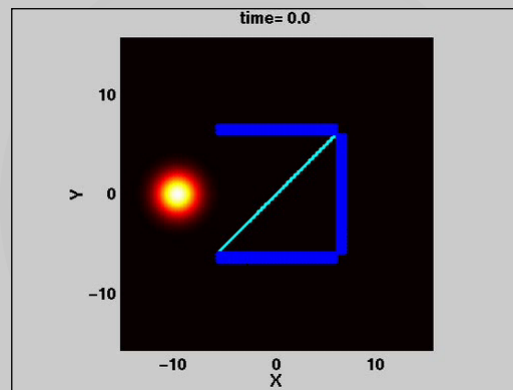
## Quantum interference I



## Quantum interference II



## Quantum interference III



## Summary

- Wave-particle dualism
- Quantum superposition principle
- Quantum interference
- Quantum entanglement
- Atom-field interaction
- Amazing quantum interference

<http://www.quniverse.sk/buzek/>

**How do we observe all this?**