

# Tutorial Schrödinger's on a Quantum Computer



THE QUANTUM LÄND  
Rydberg Quantum Computers & Simulators made in Stuttgart

Schrödinger's cat is a **thought experiment** to illustrate the strange implications that the predicted phenomena of **superposition** and **entanglement** can have. Here we illustrate the basic mechanism of the thought experiment as a quantum circuit on a **quantum computer simulator**.

More tutorials on

[www.thequantumlaend.de](http://www.thequantumlaend.de)

Try our Interactive Quantum Circuit Simulator!

## QUANTUM STATES



Qubits ("quantum bits") are described by **quantum states** (= vectors):

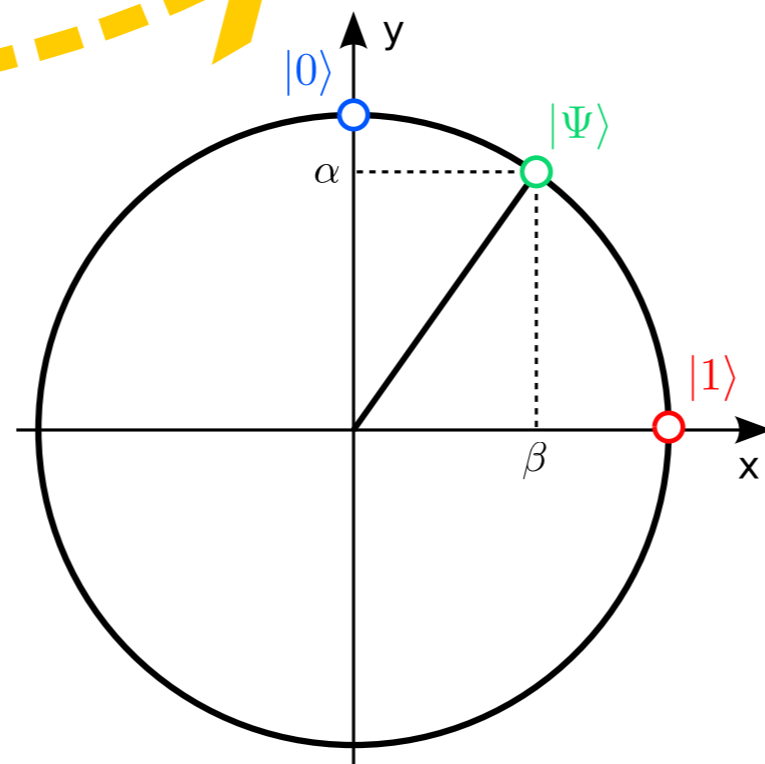
$$|\Psi\rangle = \alpha|0\rangle + \beta|1\rangle \quad \text{with} \quad \alpha^2 + \beta^2 = 1$$

Amplitudes      Basis states      Normalization

**Measuring**  qubits yields binary outcomes **probabilistically**:

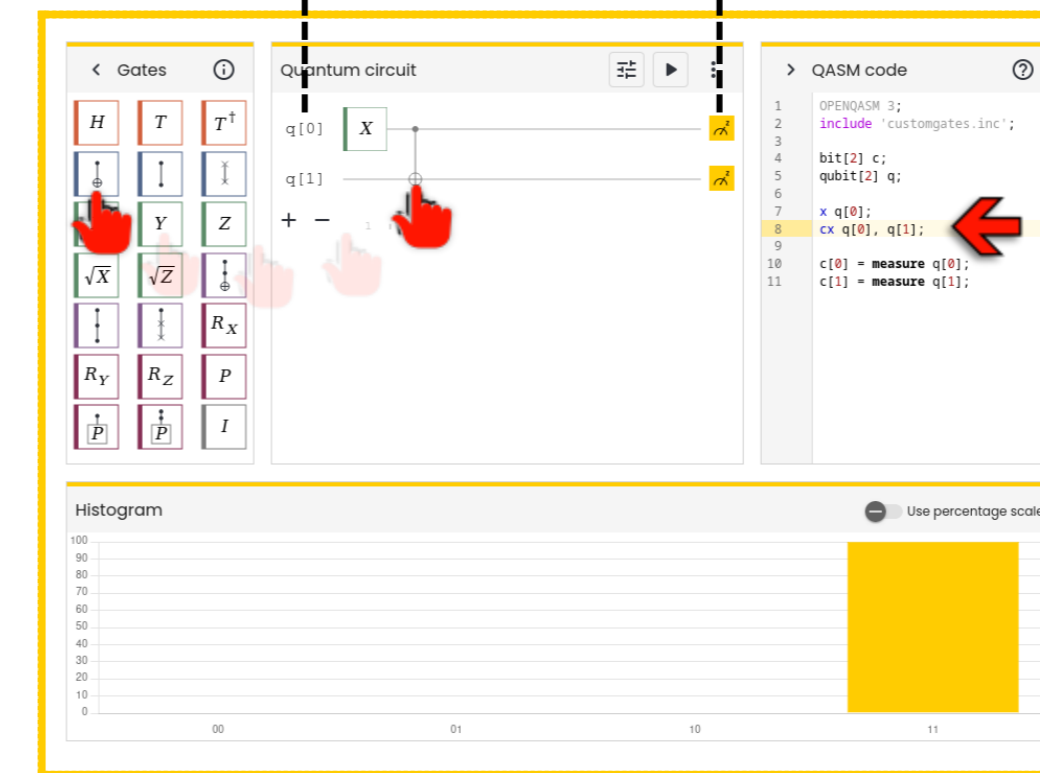
$$|\Psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

$$\begin{aligned} |\Psi'\rangle &= |0\rangle & p &= \alpha^2 \\ |\Psi'\rangle &= |1\rangle & p &= \beta^2 \end{aligned} \quad \text{Probabilities}$$

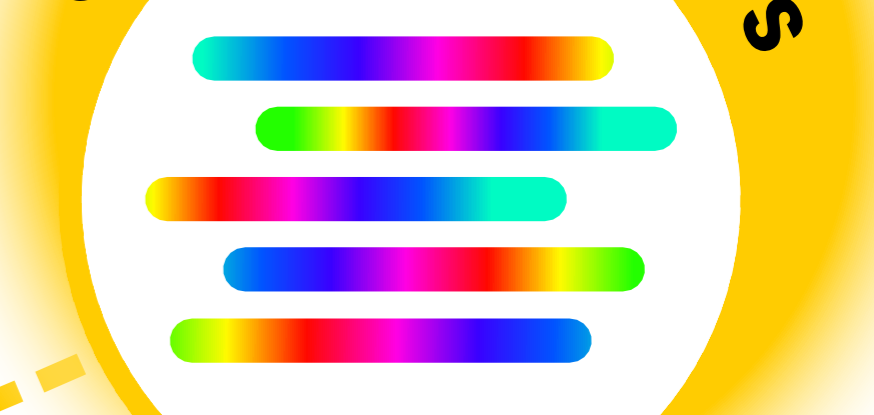


Quantum programs = **Quantum circuits**  
= Sequences of **quantum gates**

Initialization  $|0\rangle$       Measurement 



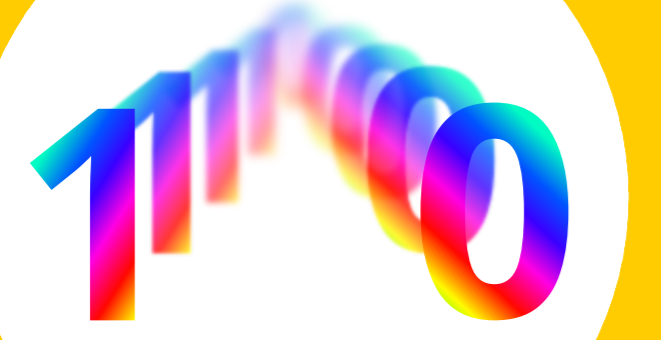
## QUANTUM CIRCUITS



Qubits can be in **linear combinations** ("superpositions") of their basis states:

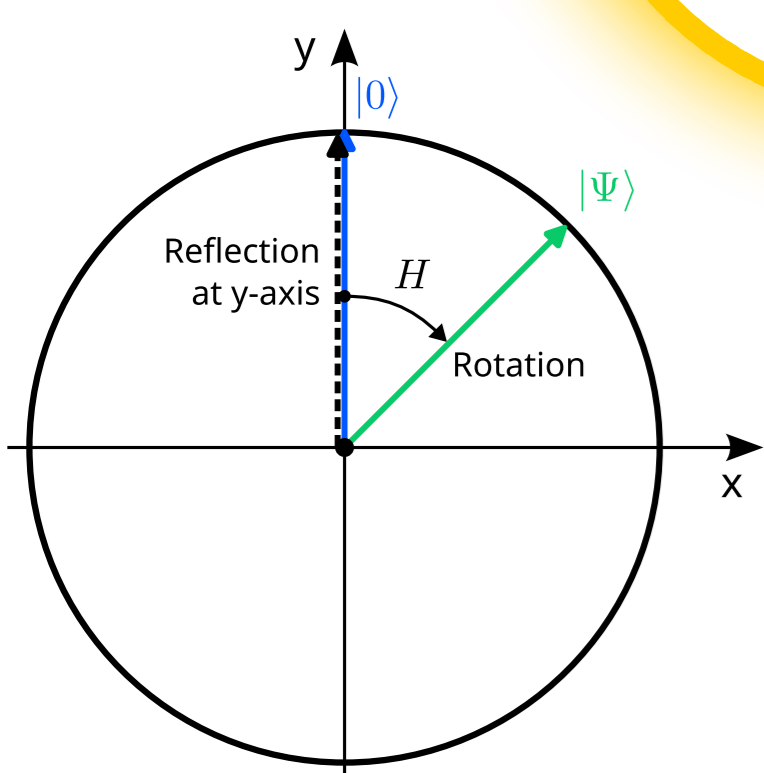
$$|\Psi\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

## SUPERPOSITIONS

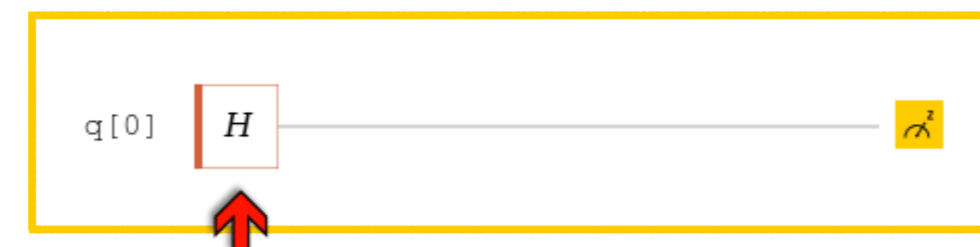


After its **half-life period** an unobserved nucleus is in the state:

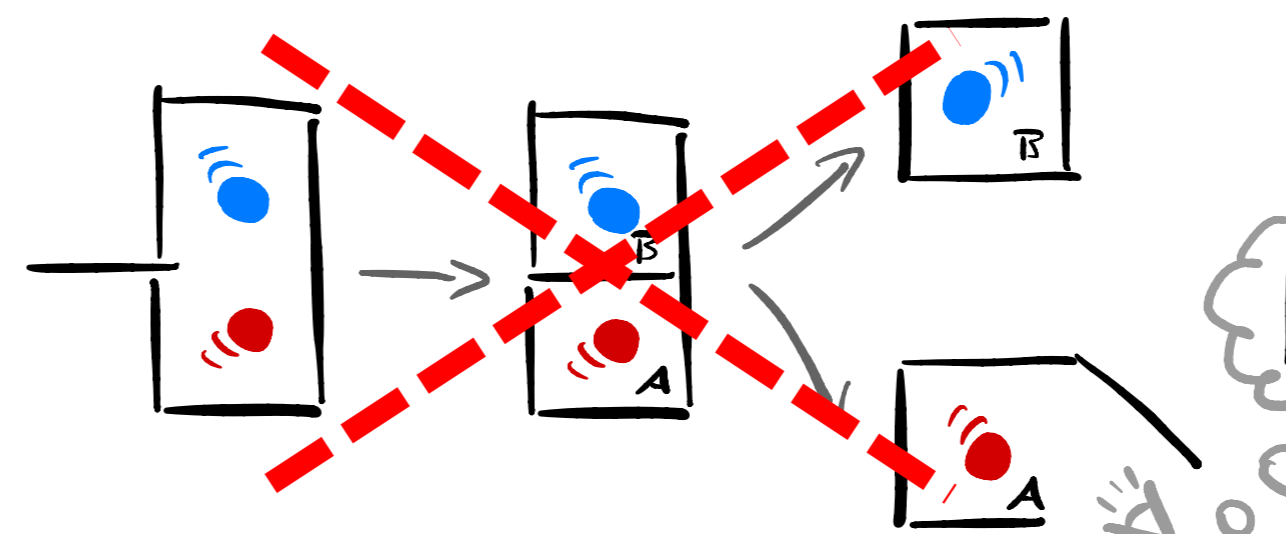
$$\left| \text{unobserved nucleus} \right\rangle = \frac{1}{\sqrt{2}} \left| \text{decayed} \right\rangle + \frac{1}{\sqrt{2}} \left| \text{not decayed} \right\rangle$$



The **Hadamard gate** creates superpositions:



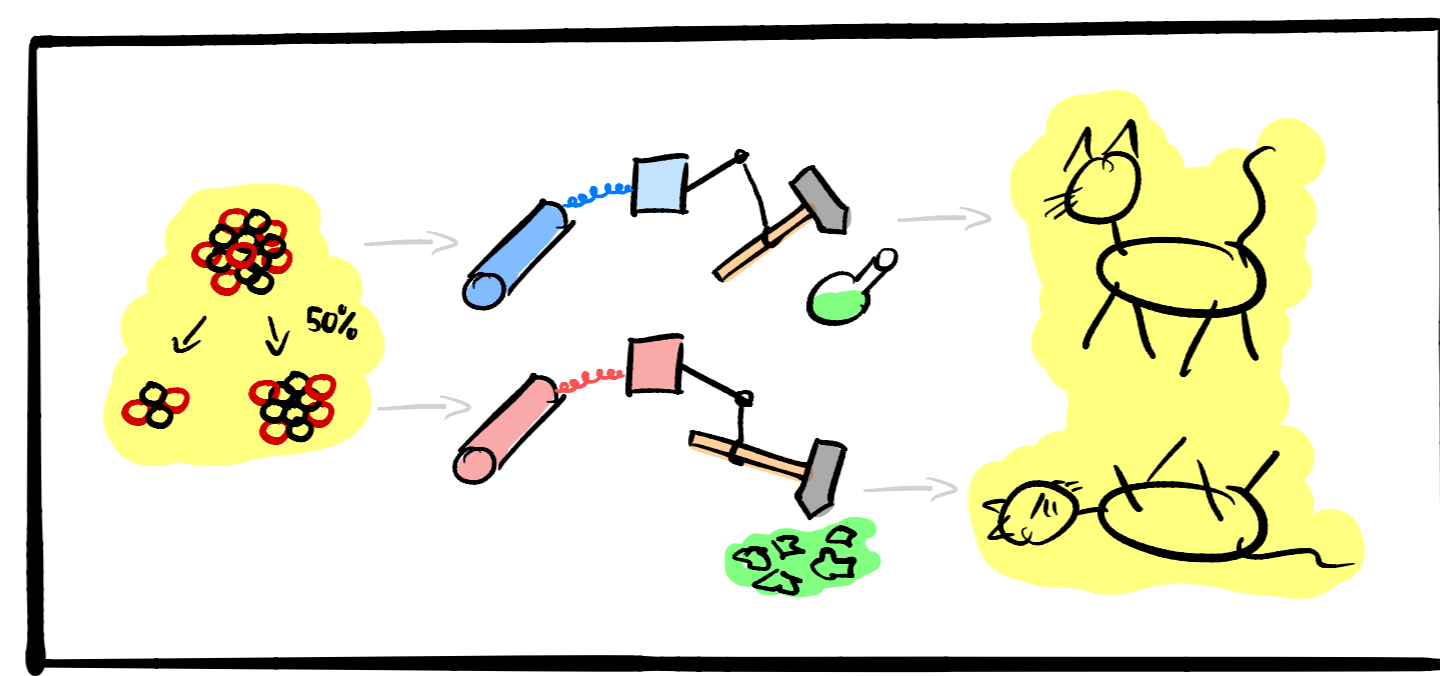
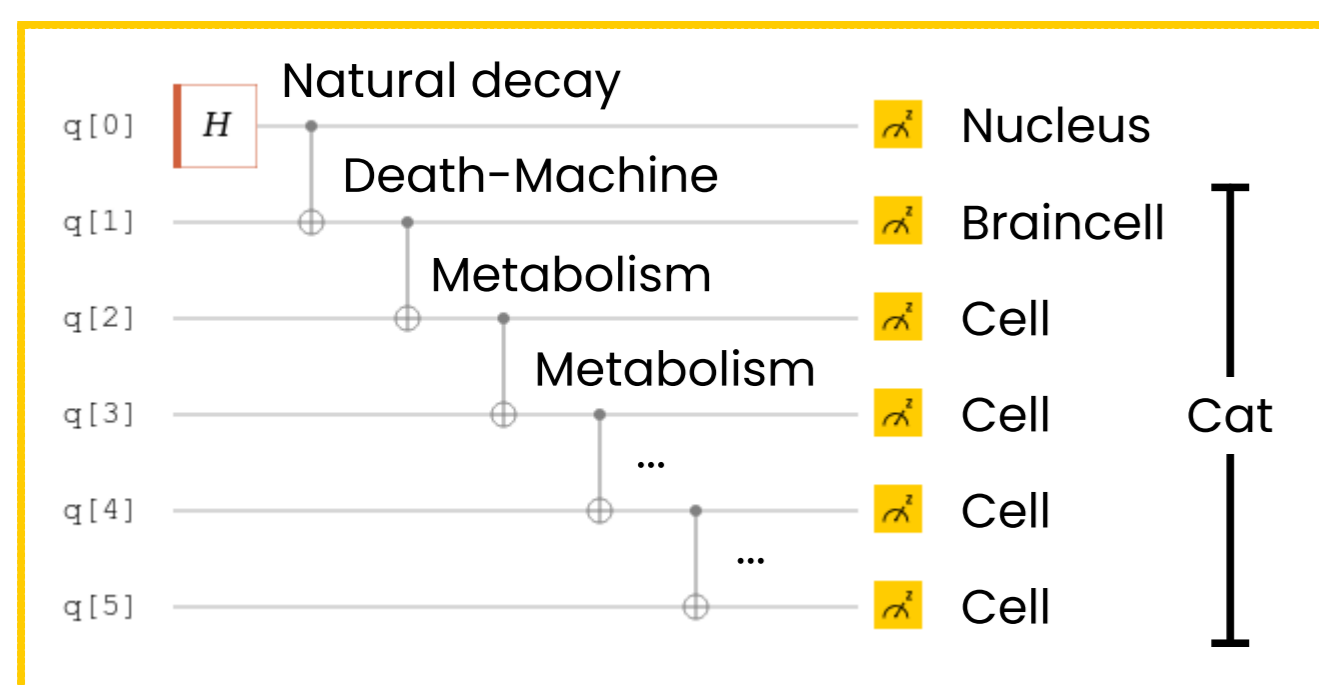
Entanglement = **Correlations** that **cannot** be realized in **locally realistic** models:



**CNOT gates** ("Controlled-NOT") can create entanglement:



Quantum mechanics implies that the **5-qubit cat** gets entangled with the nucleus:



Measuring **one** qubit of an entangled state **collapses** the whole state:

$$|\Psi\rangle = \frac{1}{\sqrt{2}}|00\rangle + \frac{1}{\sqrt{2}}|11\rangle$$

$$\begin{aligned} & \downarrow \text{Measurement} \\ & \begin{aligned} |00\rangle & & |11\rangle \\ p &= 0.5 & p = 0.5 \end{aligned} \\ & \text{Probabilities} \end{aligned}$$

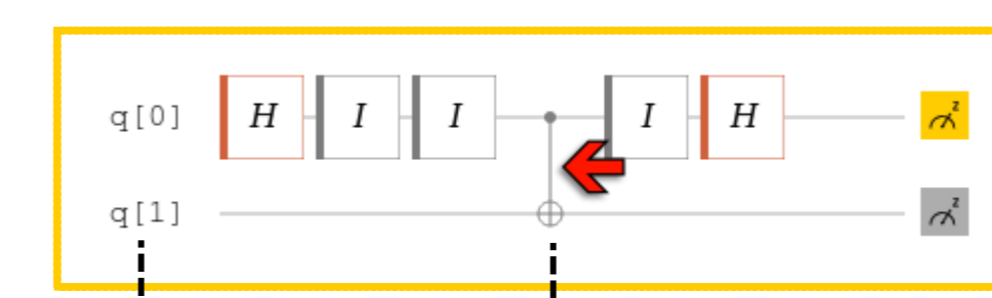
## ENTANGLEMENT



**Interference** is the hallmark of **coherence**:

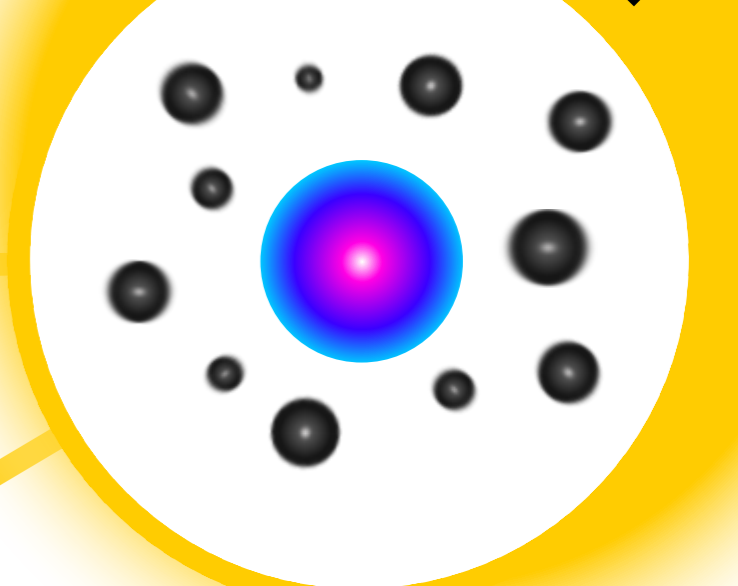


**Decoherence** destroys **interference**:



Environment      "Information leakage"

## DECOHERENCE



Due to unavoidable decoherence there would be **no superposition** of the cat in a real experiment!

What happens during a measurement in quantum mechanics?  
→ **"Measurement Problem"**

Opening the box = **Measurement** = Collapse of the quantum state:

