Quantum Labs, 2022 / Period I

Course overview

__Lecturers__: Ilkka Tittonen, Laure Mercier de Lépinay

__Assistants__: Aashish Sah, Timm Mörstedt, Aarne Keränen, Lassi Hällström, Vladimir Kornienko

12.09.2021

Aalto-yliopisto
Aalto-universitetet
Aalto University

General info

- Period I (05.09.-23.10.2022)
- 4 different experiments
- Groups of 4 students
- 3 Steps for each experiment: Labwork (all), report (choose one) and presentation (choose one)
- Time slots for Labwork can be booked in MyCourses/Scheduling, 3h/experiment
- A presentation session for each group with a talk from each experiment (in total four talks in each session)

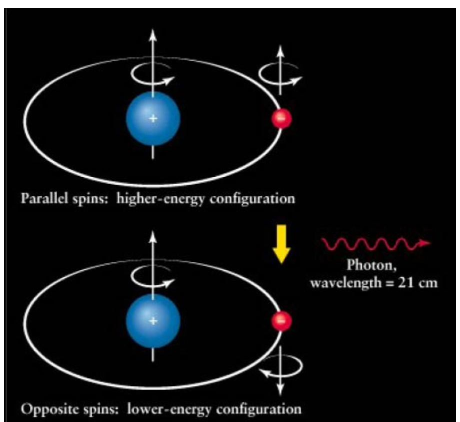
Scheduling

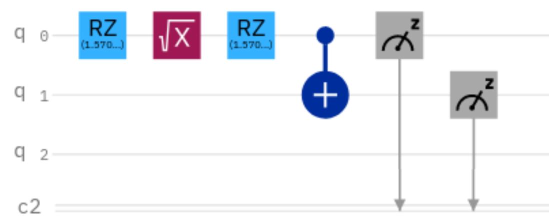
The experiments can only be done during the following dates:

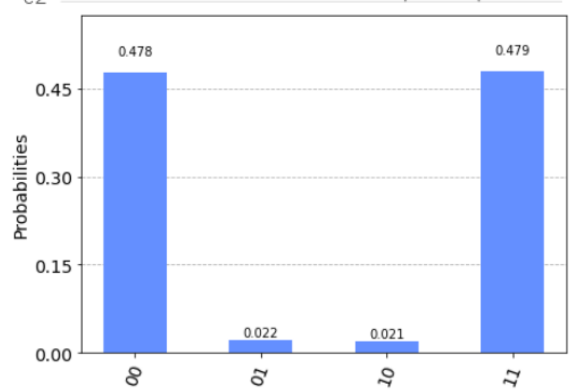
- **Experiment 1: 13.09 - 04.10.2022**
- **Experiment 2: 14.09 - 05.10.2022**
- **Experiment 3: 14.09 - 02.10.2022**
- **Experiment 4: 14.09 - 05.10.2022**

Experiment 1: Quantum Measurement with Qiskit

- Responsible TA: Aashish Sah
- Measuring the energy levels of the hydrogen ground state using IBM simulator and quantum computer







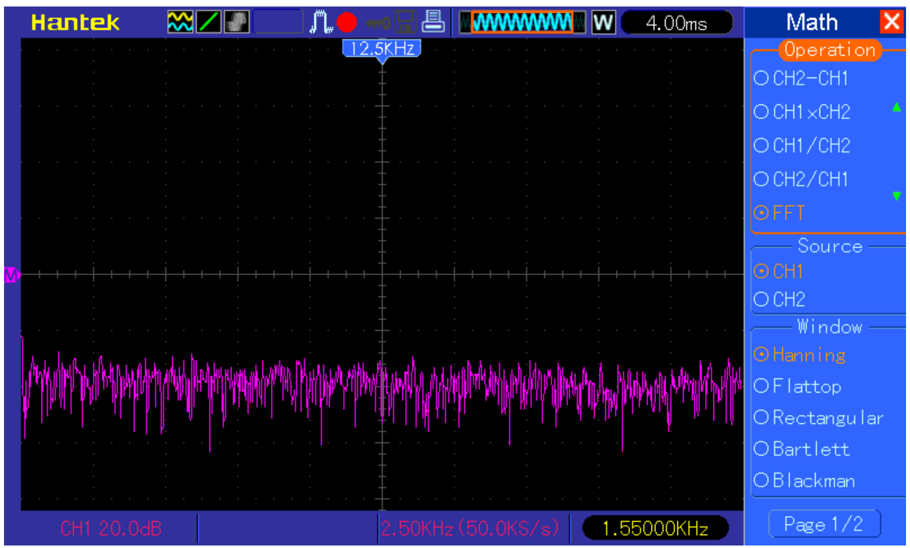
Key concepts

- Hyperfine splitting
- Single Qubit Gates
- Multiple Qubits and Entangled States
- Mitigating Noise on Real Quantum Computer

Aalto-yliopisto
Aalto-universitetet
Aalto University

Experiment 2: Temperature-dependent noise measurement

- Responsible TA: Timm Mörstedt
- Measurement of noise spectra of different resistors using a spectrum analyzer
- Measurements at RT and in liquid nitrogen

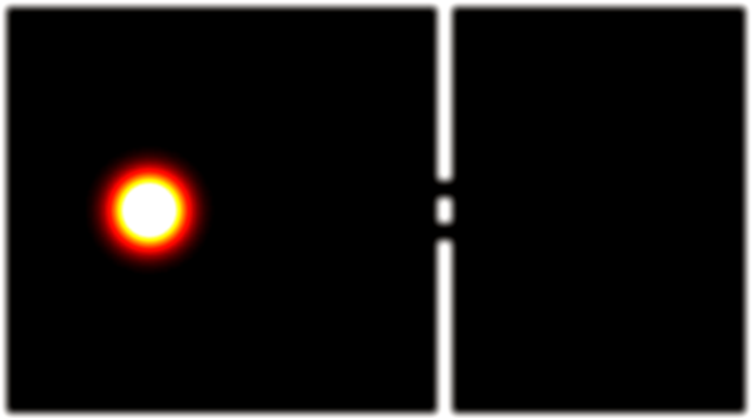


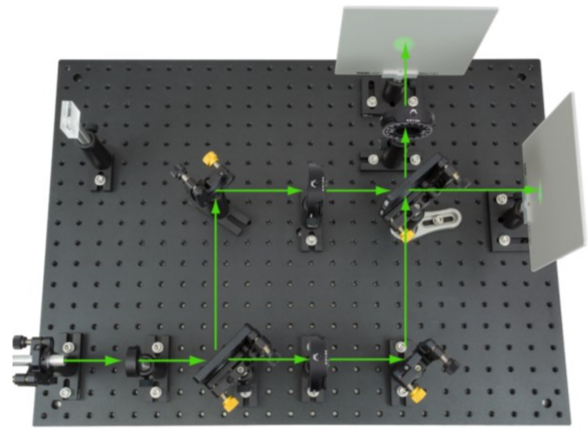
Key concepts

- Noise spectrum
- Johnson-Nyquist noise
- RF analysis: averaging, RMS
- Boltzmann constant

Experiment 3: Dual path interference

- Responsible TAs: Lassi Hällström, Vladimir Kornienko



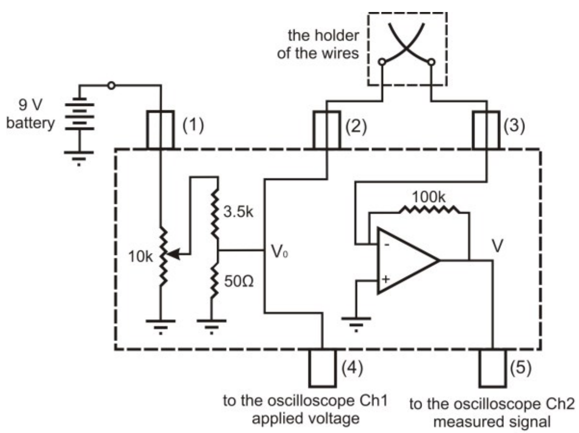


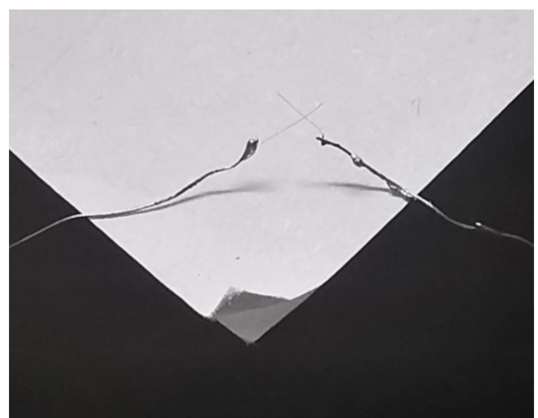
$$i\hbar\frac{\partial}{\partial t}|\Psi(t)\rangle = \hat{H}|\Psi(t)\rangle$$

Key concepts
- Wave-particle duality
- Superposition
- Interference

Experiment 4: Conduction quantization

- Responsible TA: Aarne Keränen
- Creation of gold nanowire
- Observing quantisation of conductance in gold nanowire





Key concepts

- Schrödinger equation
- Particle in square well
- Quantization of conductance

Aalto-yliopisto
Aalto-universitetet
Aalto University

Report and presentation guidelines

- Each group member writes a report on a single experiment (four reports in total per group covering all four experiments)
- Length 4–5 pages
- 1 revision possible after feedback

  (if not a serious attempt, will be given back as such with comment: “finish report”)
- DL one week after experiment, revision DL one week after feedback
- One talk per student (all four experiments covered in each group)
- 8 min talk + 2 min questions
- Templates and instructions on MyCourses

Teamwork

- Each group has 4 persons and does 4 experiments:
  - ➢ Each member of the group is the main responsible for 1 of the reports (on 1 of the 4 experiments)
  - ➢ but **ALL group members** should be involved in **each experiment**
  - ➢ 1 person's job ≠ 1 experiment
  - ➢ 1 person's job = 4 experiments + writing (most of) one report + checking/giving feedback on all reports of the group
  - ➢ Do not assign roles in advance in case one person is sick one day

- Communicate between yourselves
- For experiments in Micronova: don't be late

Report content

Focus the report on **your work**, rather than on theory

- No need to reexplain everything (for this course at least)
- Present briefly what you did/the way you did it
- Present results **with care** (see next slides)
- Discuss results
  - can you draw some conclusion from the result?
  - Is the result lower, higher, different than expected, why (do you think)?
  - Is the uncertainty particularly low or high, why?
  - Is there a systematic error, what is it, what could you do to cancel it?
  - What can be done better and how would it improve the experiment?
  - What other related experiment could you do?...

Do not copy-paste anything from any source (even Wikipedia).

Try to rephrase (sometimes difficult). At least do not ever write something you do not understand.

Uncertainty and error

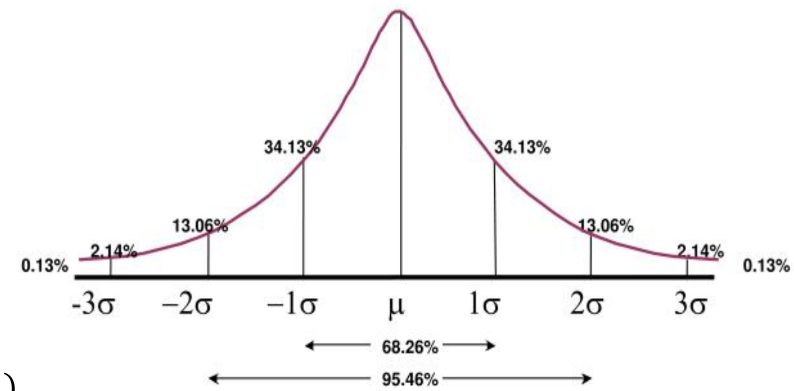
Uncertainty characterizes the estimated possible deviation between the measured and actual values. Two different types of uncertainty:

Type A (or statistical uncertainty): Uncertainty in this category is evaluated using statistical tools such as **mean** and **standard deviation**. Experiments are repeated several times under similar conditions and the outcomes are recorded.

Statistical analysis is performed on the recorded data to quantify the Type A uncertainty in the measurement.

Type B: Uncertainty of this category is based on previous measurement data, manufacturer's specification, instrument calibration, etc.

Uncertainty estimation



- When measuring a variable, always consider measurement uncertainty
- Gauss distribution $G(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)/(2\sigma^2)}$
- Standard deviation σ, 68% confidence interval
- Repeated measurement (N times)
  - Standard Error $SE = \frac{\sigma}{\sqrt{N}}$

Error propagation

$$X = a + b \rightarrow \sigma_X = \sqrt{{\sigma_a}^2 + {\sigma_b}^2}$$

$$X = ab \rightarrow \frac{\sigma_X}{|X|} = \sqrt{\left(\frac{\sigma_a}{a}\right)^2 + \left(\frac{\sigma_b}{b}\right)^2}$$

$$X = a^b \rightarrow \frac{\sigma_X}{|X|} = |b| \frac{\sigma_a}{|a|}$$

Presenting measurement results

- A measurement result should have a **unit** (in most cases)
- Use **consistent** units throughout the report (avoid conversions back and forth between radians and degrees)
- Use "**reasonable**" units:
  - **SI** if possible (m, s, A, kg, K, … Newton, Joule, etc).
  - Numbers should be **readable by humans** (1300000 Hz -> 1.3 MHz)
  - Alternatively: 1.3×10^6 Hz
  - Present the **uncertainty** at least on important results: 10.4 ± 0.2 V
- **Round** numbers as necessary:

  134.567354 ± 1.2 V ✖

  134.6 ± 1.2 V ☺

Presenting graphs

- **label both axes in a clear way:**
  - "Voltage" might be confusing if there are 2 relevant voltages in your experiment that this graph could represent. Use:
    - ➢ "Excitation voltage (V)" OR
    - ➢ "V_a (V)" if you have defined V_a elsewhere
  - Do not count on the text to replace the labels on the axes:
    - "The graph above represents the current as a function of the voltage"
    - "As can be seen on the graph above, the voltage is a linear function of the magnetic field"

    You *can* write such sentences if you like but the axes of the graph still need to be labeled.

- **Include the units in the axis label whenever relevant, e.g.:**
  - ❖ "Excitation voltage (V)" or "V_a (V)" if you have defined V_a elsewhere
  - ❖ "Number of occurrences" (no need for a unit, unit is "1")

Feedback