

## milq – Quantum Physics in Secondary School

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# The aims of the milq project

(milq = **M**unich **I**nternet Project to **L**earn **Q**uantum Physics)  
established c. 1999

## Principle aim:

Convey the **modern world view** of quantum physics to secondary school students

Conceptual approach to quantum physics

Qualitative reasoning based on **reasoning tools** (basic rules of quantum physics)

Use of interactive simulation programs (double slit, Mach-Zehnder interferometer)

Available in English since last year:  
<http://milq.tu-bs.de/en>

## Lesson 7: Heisenberg's uncertainty relation

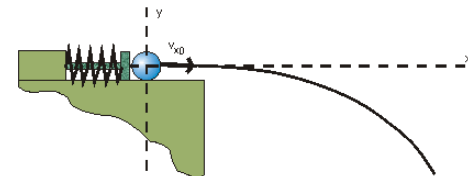
- 7.1 Simultaneous preparation of different properties – 7.2 Preparation of position and momentum for photons – 7.3 A measure for the "quality" of a preparation
- 7.4 Measurement method and properties – 7.5 Electrons at the single slit and quantitative expression of the uncertainty relation
- 7.6 Uncertainty relation and path concept – 7.7 Progress check – 7.8 Summary

The Heisenberg uncertainty relation is often seen as one of the most important insights of quantum mechanics. This chapter shows how it can be expressed as a statement about the ability to simultaneously prepare properties.

You can download the slightly more detailed Chapter 7 of the teaching materials as a pdf file to help you.

### 7.1 Simultaneous preparation of different properties

In preparation for understanding the Heisenberg uncertainty relation, we will again discuss the preparation of properties concept (preparation).



# Outline of the milq course

## milq: a spiral approach

### *Part 1: photons*

1. Photoelectric effect
2. State preparation

#### **Mach-Zehnder interferometer**

3. Wave- and particle-  
behavior
4. Non-localised photons
5. Probabilistic  
interpretation

### *Part 2: electrons*

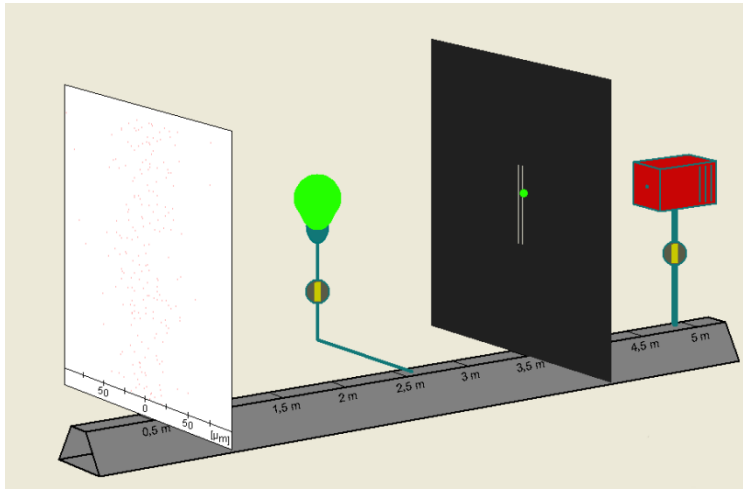
6. Electron diffraction

#### **Double-slit experiment**

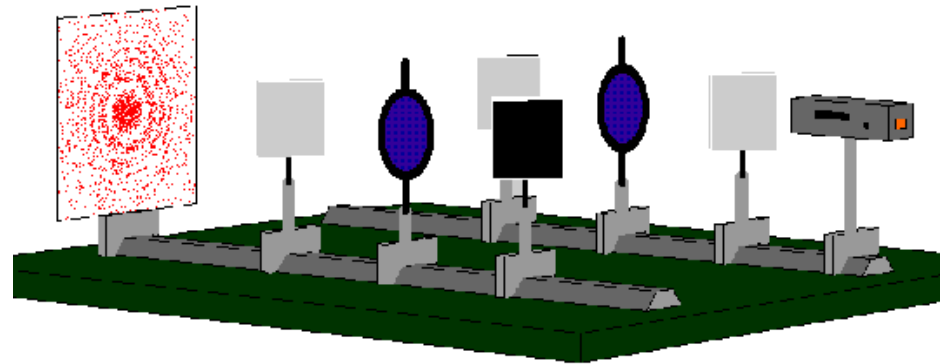
7.  $\psi$  and its meaning
8. Non-localised electrons
9. Measurement process
10. Schrödinger's cat &  
decoherence
11. Uncertainty relation

# Simulation programs

## Double-slit experiment



## Mach-Zehnder interferometer



# Reasoning tools

In quantum physics: Proper language is crucial

## Reasoning tools:

A set of four qualitative rules: The basic traits of quantum physics

„Qualitative mini-axiomatic“ provides students with a verbal tool they can use in discussions and argumentations.

Enable students for qualitative discussions, predict quantum effects, help to avoid learning difficulties.

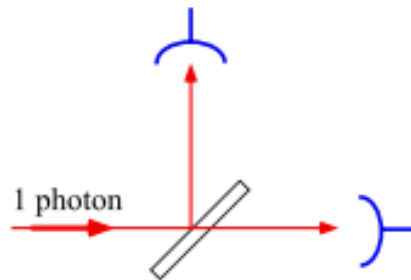
# Reasoning tools

## Rule 1: Statistical behavior:

A result of a single event cannot be predicted, it is random!

Only statistical predictions (for many repetitions) are possible in quantum physics.

Example: Anticoincidence of single photons at a beam splitter



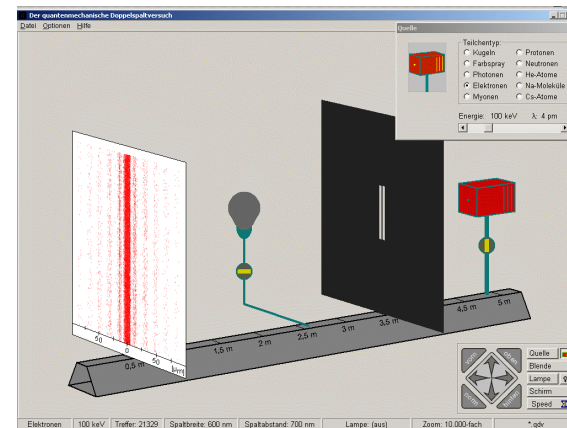
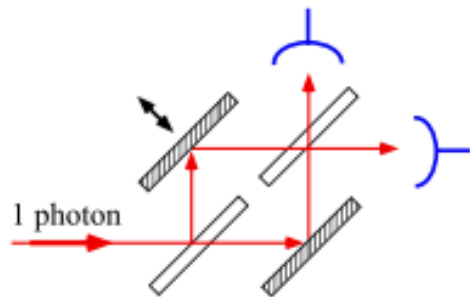
# Reasoning tools

## Rule 2: Single quantum objects can contribute to an interference pattern.

Interference occurs if there is **more than one classical alternative** leading to the same experiment result.

Superposition states: None of these alternative will be “realized” in a classical sense.

Example: Two paths in an interferometer; two-slit interference





# Reasoning tools

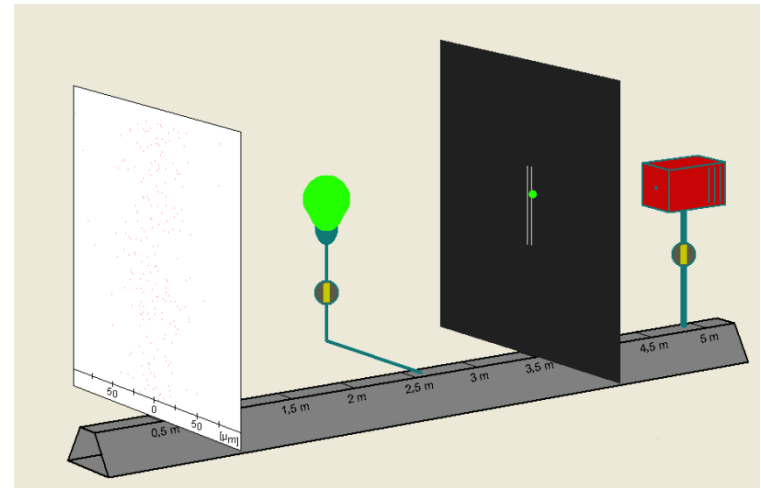
## Rule 3: Unique measurement results

Even if a quantum object in a superposition state need not have a fixed value of the measured quantity, you always find a unique measurement result.

This is the measurement postulate of quantum mechanics

Example:

- Stern-Gerlach experiment,
- Feynman's light bulb



# Reasoning tools

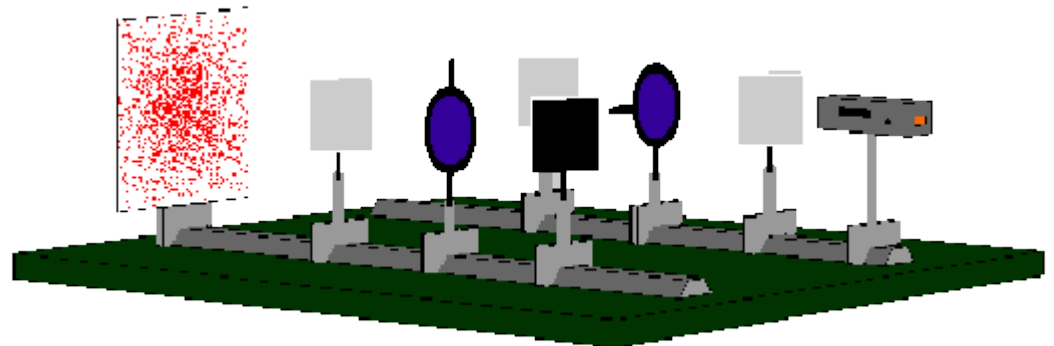
## Rule 4: Complementarity

Which-way information and interference pattern are mutually exclusive.

Quantum objects can not be prepared in a defined position with a defined momentum at the same time.

Examples:

- Heisenberg's uncertainty relation
- Quantum Eraser experiments



# Future developments

In view of EU's prospected need for Quantum Technology workforce:

- The conceptual approach of milq is well-suited for **creating „quantum awareness“**
  - Qualitative reasoning tools can form a **basis for intuitive understanding**
- promising starting point for the education and training of **„Quantum Engineers“**

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