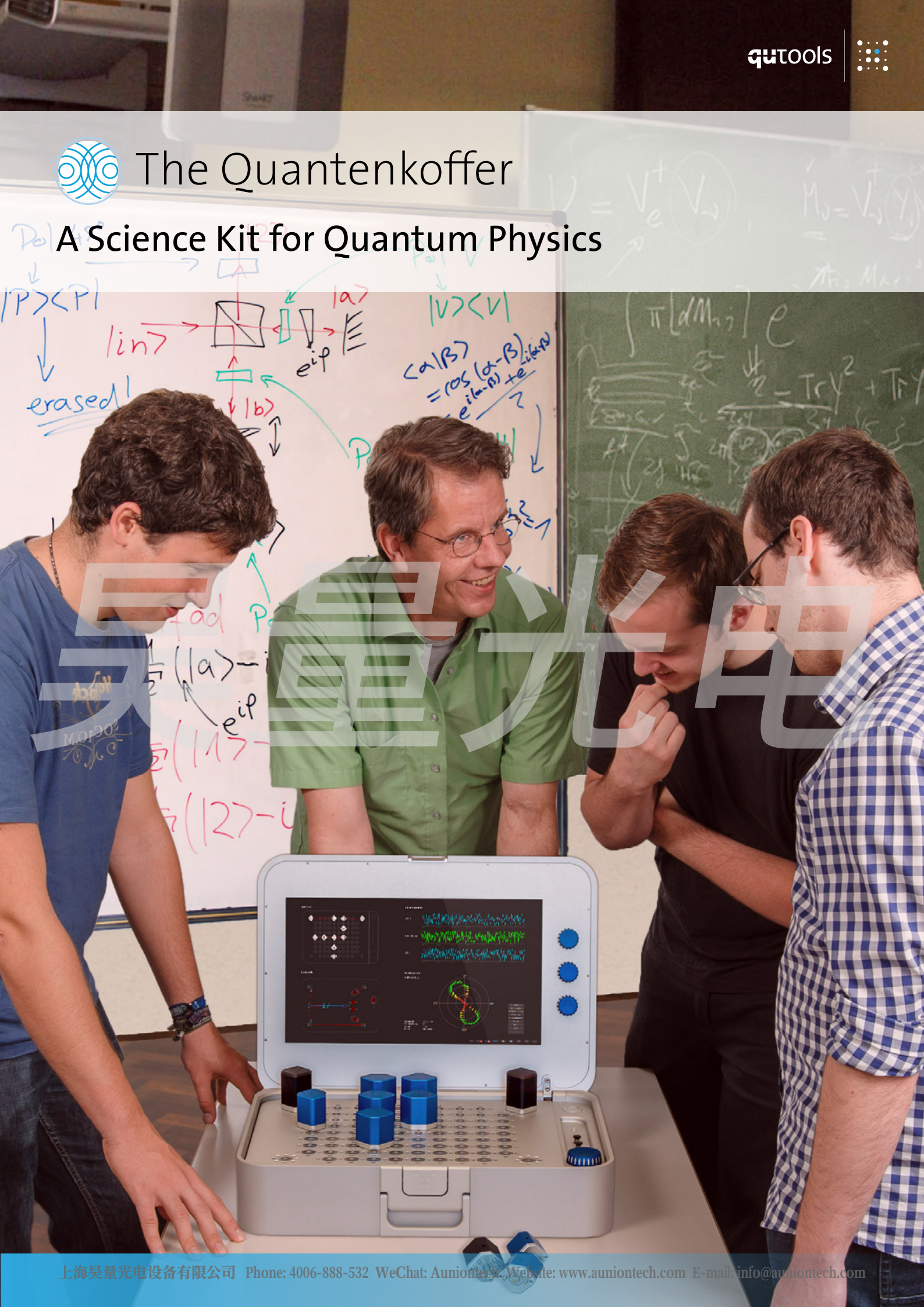
qutools

The Quantenkoffer

A Science Kit for Quantum Physics



Quantum Physics - Revolution of our Worldview

Describing the world exactly in all its details has always been the ambition of physics. But quantum physics pushes the boundaries of this view and opens a completely new perspective.

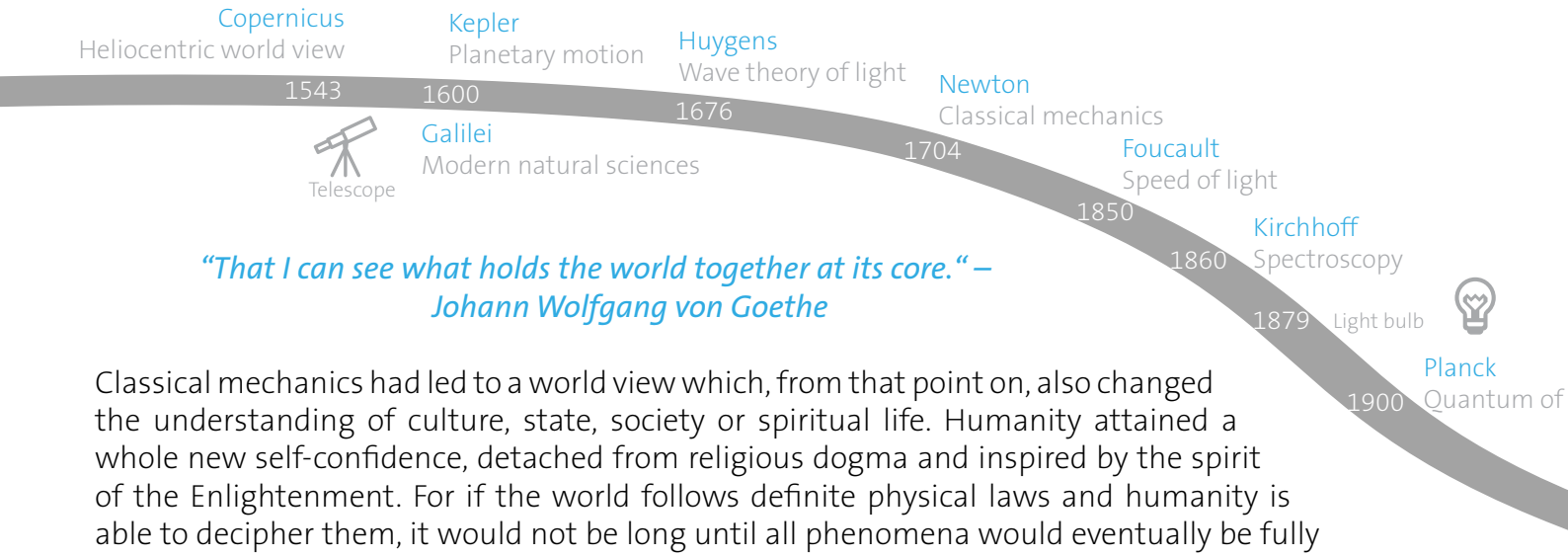
There is hardly anything that has preoccupied mankind as much as light. Whether it is described in the Bible as the origin of all life, or by the philosophers of antiquity as a symbol for absolute knowledge, whether we describe certain historical periods as "Dark Ages" or the age of reason as "Enlightenment" - in the struggle for knowledge, faith and our place in the universe, light has always been a welcome metaphor.

"Let there be light! And there was light." –
Old Testament, The First Book of Moses

"A missionary of the Middle Ages recounts that he had found the point where the heavens and Earth touch each other..." –
Camille Flammarion: L'atmosphère, Paris 1888, Coloration: Hugo Heikenwaelder, Vienna 1998.

However, light only became a subject of investigation as the modern natural sciences, particularly physics, started rising and developing.

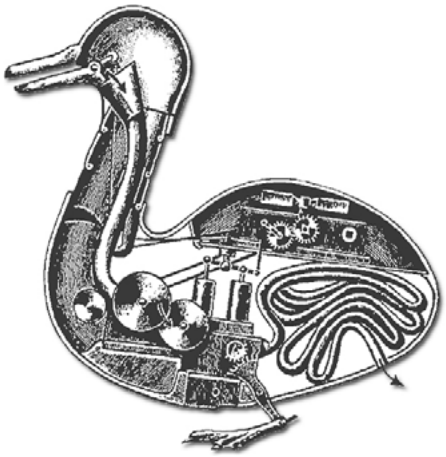
Up to the mid of the last century though, it was still relatively unclear what light actually was. Its accurate exploration was only made possible by an understanding of science that had its origins in the early stages of the Enlightenment: the reduction of observations to simple laws - a principle also used by Isaac Newton in the formulation of classical mechanics.



"That I can see what holds the world together at its core." –
Johann Wolfgang von Goethe

Classical mechanics had led to a world view which, from that point on, also changed the understanding of culture, state, society or spiritual life. Humanity attained a whole new self-confidence, detached from religious dogma and inspired by the spirit of the Enlightenment. For if the world follows definite physical laws and humanity is able to decipher them, it would not be long until all phenomena would eventually be fully explained and predicted.

And so began during the Enlightenment a scientific quest for causality. The aim was to put everything into relation to one another, such that, as Goethe puts it, it would be possible to find out "what holds the world together at its core".



In 1738, Jacques de Vaucanson created in Paris a mechanical duck which fluttered its wings, drank water and even had a digestive tract. His dream was to create an artificial man - Mechanical Duck, Jaques de Vaucanson, 1738.

There lies a certain irony in the fact that light served as the first source of evidence for undermining this world view at the beginning of the 20th century, through the rise of quantum physics. Suddenly, there were theories that, under certain conditions, refuted the assumptions previously anchored in classical mechanics and in the theory of relativity. The unambiguous determinability was replaced by uncertainty and the exact calculation was replaced by probability.

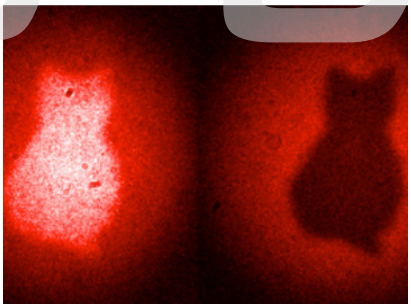
"God does not play dice with the universe" – Albert Einstein

Where the former principles promised to determine movement curves of flying objects - such as a celestial body - precisely, quantum theory limits itself to the prediction of curves weighted with probabilities. An understanding that shocked the physical world at the time. "God does not play dice with the universe" is one of Albert Einstein's most famous quotes, who himself made valuable contributions to quantum physics. Also the phrase „spooky action at a distance" that refers to the completely new phenomenon of entanglement belonged to Einstein's view.

As many puzzles as quantum physics posed, its benefits are obvious: in everyday life it meets us in most technical devices, in electronic semiconductor elements and that way in every microchip, in magnetic resonance tomography, but also in lasers or light-emitting diodes. Quantum physics is therefore one of the best experimentally tested theories in physics.

"Understanding often goes much further than reason" – Marie von Ebner-Eschenbach

However, that has not led yet to the questioning of the absolute, deterministic conception of the world and the universe. Quantum physics is now over 100 years old and it is very easy to find many good quotes by its founders from the time of the beginning. In this day and age however, its understanding is limited to peripheral areas of physics and has not yet really come to enter other sectors of society. For that to happen, young people should come in touch with quantum physics and have the chance to understand its phenomena using a learning-by-doing approach. This is the "Enlightenment claim" of the Quantenkoffer.



Viennese researchers play on "Schrödingers Cat" with entangled photon pairs and an aperture. The red photons never "interacted" with the object, but they show the cat shape - Patricia Enigl, IQOQI, Vienna.

action

1905 Einstein – Light quantum

1913 Bohr – Atom model

1926 Schrödinger – Wave mechanics

1927 Heisenberg – Uncertainty principle

1945 Transistor

1947 Feynman – Quantum electrodynamics

1954 Solar cell

1960 Laser

1964 Bell – Inequality theorem

1970 Microprocessor

2011 Adiabatic quantum computer

The Quantenkoffer

Quantum physics science kit for a multitude of experiments with single photons and entangled photon pairs.

A key feature of the Quantenkoffer is its flexibility with regard to generation and detection of visible laser light, single photons and even entangled pairs. Its optical elements, mechanical components and digital circuits are seamlessly integrated in order to cover a range of experiments and topics of quantum physics as wide as possible.

Source for Single Photons and Entangled Photon Pairs

A pulsed laser and optical crystals form the core of the photon source, placed below the surface plate within the case. Single pairs of photons are generated through nonlinear processes within optical crystals in the near infrared.

Automatic Adjustment

Its completely automatic adjustment through servomotors and sensors facilitates the setup of experiments and the quick realization of measurements, allowing for the playful immersion into the fascinating world of quanta.

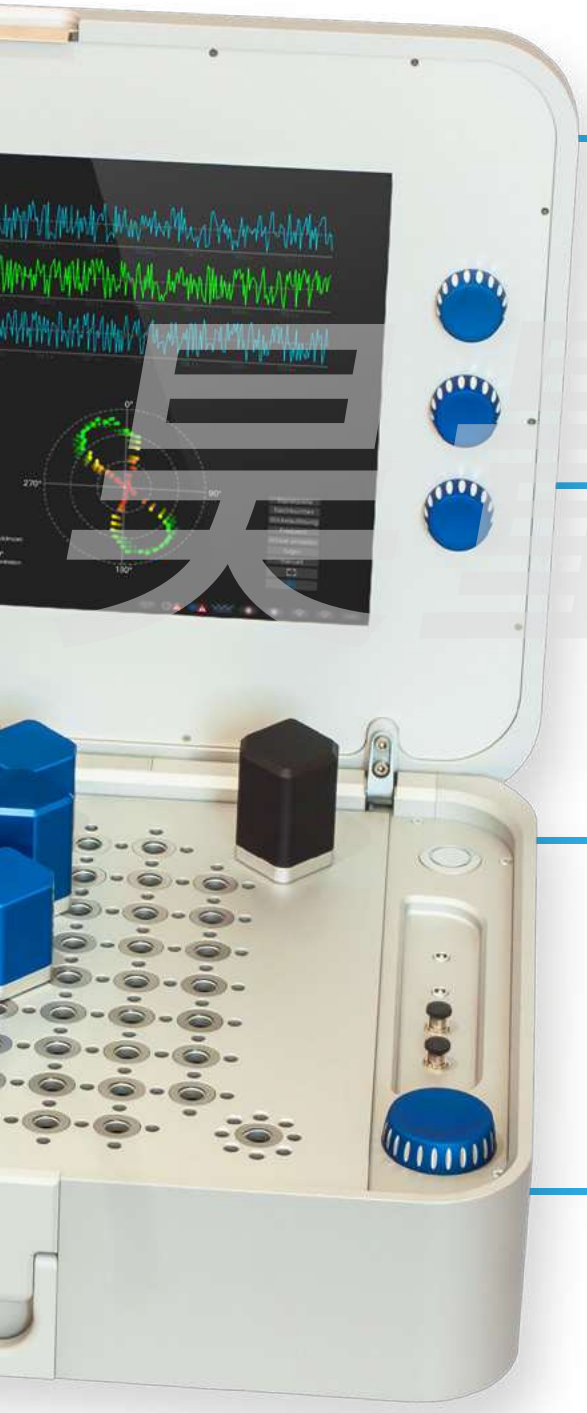
Experiment Flexibility

On the high precision board with 86 slots, tokens can be positioned arbitrarily. Their different properties make it possible to conduct experiments from 100 years of quantum physics as easy as playing. Various setups can be built and individually created.

Single Photon Detectors

Extremely sensitive yet robust avalanche photodiodes are part of the measuring unit of the Quantenkoffer. This enables the detection of single photon pairs, as well as the measurement of bright light sources with high intensities at a high time resolution.

Mobile, flexible and quickly ready to use - become part of the fascinating world of modern physics, explore the world of quanta through playing and perform the most complex experiments with the Quantenkoffer.



Time Resolution in Picosecond Range

The ultra-fast processing of the measured events, enabled through powerful digital technology, allows the detection of time differences in the picosecond range, for example to measure the speed of light in a setup on the board with few tokens.

Universal Use

The versatile interfaces such as WLAN, Bluetooth, HDMI and USB allow the connection to various devices such as tablets and projectors. Therefore, the Quantenkoffer also offers presentation possibilities, as well as simple data exchange.

Intuitive Operating Concept

The user-friendly software is supported by manuals, exercises, lab tutorials in addition to several Apple and Android apps. These can be used for the remote control of the Quantenkoffer via tablet and for the evaluation of measurement data.

Robust and Safe

The sensitive optics and sensors are mounted safely and shockproof in the interior of the robust case. The integration of the powerful laser source below the playing surface enables a safe handling of the laser radiation.

Experimenting with the Modular Science Kit

Learn complex topics in guided experiments or use your own creativity to discover physics.

The quantum eraser experiment can be performed with two periscopes and a total of nine tokens. If desired, the system displays which tokens are still missing and whether the previous structure is correctly adjusted. The app also provides theory and instructions throughout the individual experiments.

The Quantenkoffer and its modular design offer different approaches. You can choose to follow ideas and well-known experiments from 100 years of quantum physics, or you can use its intuitive software and design experiments from scratch.

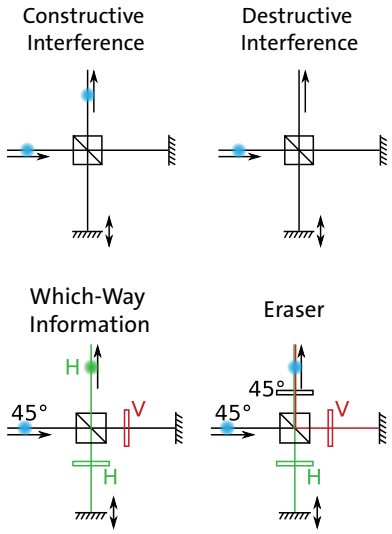
After the automatic detection of the inserted tokens, the Quantenkoffer activates the appropriate display and measuring instruments. In free mode, you can also unravel the peculiarities of the quantum world on your own.

However, it is also possible to let yourself be guided by one of the many experiments that have already been prepared. In this mode, the software offers assistance for the construction, adjustment and execution of the experiment. The Quantenkoffer selects appropriate display options and measuring settings to obtain the best possible results and guides the user through all the steps of the experiment. In combination with a comprehensive theoretical chapter, including interesting questions from the handbook, the guided-mode makes the most important experiments of quantum physics accessible even without prior knowledge. Additional materials such as worksheets and lecture notes facilitate teaching with a Quantenkoffer.

An example of an amazing experiment is the so-called quantum eraser, which is based on a Michelson interferometer. In this modified Michelson interferometer, a photon shows interference only when, after passing through the interferometer, no information about the path of this quantum object can be gained.

As soon as it can be decided from which of the two interferometer arms the photon has to come out, the interference disappears and the course of the measurement signal is constant. The path information can, for example, be determined by the polarization of a photon.

However, this polarization information can be “erased“ again, if after the merging of the two interferometer arms but before detection of the photon, another polarizer is placed at a certain angle. In this case, the interference pattern is visible again!

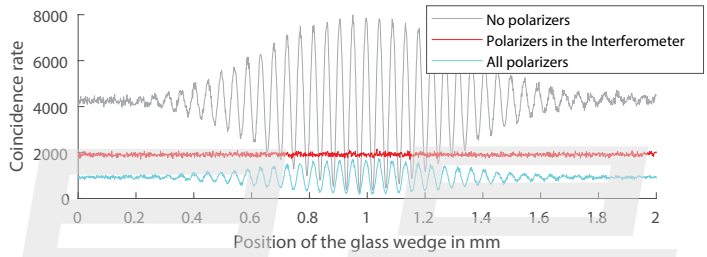


The theoretical chapters in the handbook explain the investigated matter in detail, supported by schematic illustrations and photos, like the quantum eraser experiment here.

So, as long as the photon has not been detected and it has not yet interacted with many other objects, nothing has yet been decided.

Besides the complementarity – either interference is present or information about the path is available – the installation can raise and answer further questions as well. What happens if the taken path can be determined with a certain probability? Why is it impossible to erase the information after the detection of a photon? Which properties of the photon source can still be determined from the measurement data?

For delayed evaluations, the software of the Quantenkoffer offers the possibility of storing the measured data or exporting it to external devices such as tablets. The measurement data can also be conveniently processed through the Quantenkoffer-app from several devices simultaneously.



The stored measured values have been here further processed and analyzed with a computer. For a fast analysis or as an example or suggestion, for many experiments there are also common scripts like MATLAB and Octave available besides the evaluation app.

In a nutshell: Quantum Eraser

- *Experiment with single photon interference.*
- *Complementarity: when having which-way information the interference pattern disappears.*
- *After deleting the information, the interference is restored.*
- *This effect works since the information is still "attached" to the photons and has not been yet "decohered" in the environment.*
- *The manual contains the corresponding theory, the evaluation-app allows calculations of coherence length and wavelength.*

Exciting experiments that reveal the essence of quantum physics

Beginners — *Advanced* — *Professionals*

Bell Inequality
Single Photon Spectrometer
Fourier Spectroscopy
Non-classical Correlations
Random Number Generator
State-Tomography
Speed of Light
Michelson Interferometer
Franson Interference
Detector Efficiencies
Quantum Eraser
Instantaneous Polarization Measurement
Interaction-free Measurement
Measurement problem
Hanbury-Brown-Twiss
Uncertainty Principle
Projection Measurement
Single Photons
Hong-Ou-Mandel Effect
Polarization
Polarimetry
Double Slit Experiment
Quantum Eraser in HOM
Waveplates
Quantum Cryptography

The many prepared experiments for all levels of difficulty enable a comprehensive preoccupation with the characteristics of quantum physics and their technical application.

Variety of Optical Tokens

Perform experiments with a wide range of different tokens and create exciting setups yourself.

Several optical tokens can be freely placed on the board and combined into various experiments. In addition to optical elements, the tokens contain sensors and microprocessors through which the Quantenkoffer can recognize, readout and digitally control them.

Periscope

- Connects board to source and detectors
- High-precision: Simply plug in and get started
- Two to four periscopes needed on the board for all experiments

Mirror 45°

- Deflects the beam by 90°
- Fine adjustment, manually or motorized
- Basic token for many experiments such as interferometer and speed of light

Beam Splitter

- Splits or merges the laser beam
- 50:50 or polarization-dependent
- Basic token for interferometer and random number generator

Mirror 90°

- Reflects the beam in itself
- Optionally adjustable in beam direction
- Essential for the Michelson interferometer and quantum eraser

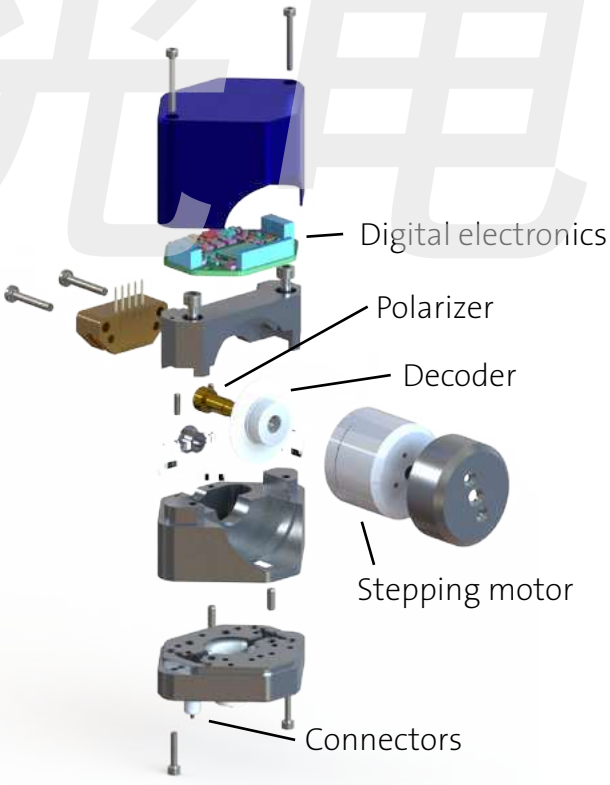
Waveplate

- Lossless polarization manipulation
- λ/2 or λ/4 integrated plates
- For advanced polarization experiments such as quantum cryptography & tomography

Polarizer

Properties

The polarization of a transverse wave - such as light - describes the direction of its oscillation. This token transmits the light of a certain polarization.



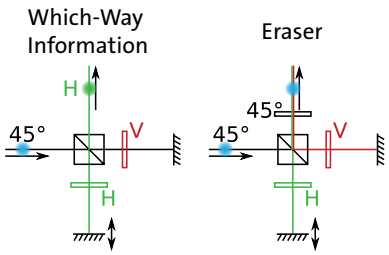
Application

This basic token constitutes the basis for all polarization experiments such as Bell's theorem, quantum eraser and quantum cryptography.

Versatile, modular and playful to operate – due to the large number of different tokens, both the most famous experiments and the ones that you design yourself can be conducted, without limiting your creativity.

Assembly & Handling

The core of this token is a polarizer, mounted on the optical axis. This optical filter can be rotated by hand or through the integrated stepping motor controlled via the Quantenkoffer or the tablet app. Inside the token, next to the electronics assembly, a decoder is located for reading the current angular position of the polarizer. Through the connectors on the bottom side, the Quantenkoffer recognizes the position and type of the token, which makes the design of complex setups and experiments user-friendly and playful.



Glass Wedge

- Changes the optical path length
- Offset adjustable with µm accuracy
- Special token for interference experiments, Hong-Ou-Mandel effect

Double Slit

- A classic for interference phenomena
- Different slit widths, grids, individual slits
- Special token for double-slit experiments with single photons or bright light

Camera

- Measurement of the laser beam
- View via display & external devices
- Beam adjustment, interference phenomena with bright light

Fiber Coupler

- Couples the beam into optical fibers
- Efficient, automatic fiber coupling possible
- Enables the connection of further detectors and the combination with external setups

Tunnel Effect

- Distance-dependent prism transmission
- Controlled via Quantenkoffer & external devices
- Special token for the tunnel effect based on the frustrated total internal reflection

Observe - Experience - Change!

Quantum physics thrives on observation. Imparting it in an understandable way encourages not only enthusiasm for natural sciences, but can also generate real value for the society.

The discovery of quantum physics over 100 years ago represents more than just a change of knowledge in the natural sciences. The entire world is now beginning to reevaluate its relationship to our surroundings and the environment. After centuries of resource exploitation as a result of the industrial revolution, today the environmental protection, sustainability and the search for alternative forms of energy have become firmly anchored in the social consciousness. And the natural sciences will play a central role in achieving these goals.

GaudiLab, Herrndorff/Shutterstock.com

Politics and business have also joined forces as, for example, numerous initiatives for the promotion of MINT subjects in schools show. But in order to be able to change the world positively, one should first understand it - or at least become aware of where today's knowledge has its limits. The confrontation with the mysteries of quantum physics can thus contribute decisively to arouse curiosity for natural sciences and convey early on an understanding of the nature and configuration of the universe.

Quantum physics changes our view on the world

In order to convey the importance of quantum physics to future generations, it is necessary to make its basic principles accessible to society as a whole. This doesn't work only with theory, but rather through practical mediation.

The Quantenkoffer enables a practical revision of the basic principles of quantum physics and ensures that this knowledge reaches the people - in schools, universities, but also into public space. The experiments that can be carried out with it are so diverse, that its possibilities of use are also very flexible:

Through "Quantenmobiles" – vehicles equipped with the Quantenkoffer – designed to bring the knowledge of quantum physics beyond small school classes or seminars, a small investment can help reach a large group of people - for example at science fairs, MINT-promotion initiatives, girls' days and many other events that encourage scientific thinking.

Matej Kastelic/Shutterstock.com

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The mobile demonstration lesson should be only the beginning though. The purpose of the Quantenkoffer is not just to fascinate young generations about quantum physics. By interacting with quantum physics basic principles, people of all ages and levels of experience gain valuable knowledge which should be available in a broad range.

The aim is making quantum physics permanently accessible and tangible, either by establishing local training centers or by using the Quantenkoffer in adult education centers or presenting it at exhibitions and fairs. Additionally, the possibility of on-site loaning also makes it possible to bring the knowledge to enterprises, associations and all other institutions - without complex experimental set-ups, complicated theory or long lecture series. Thus, with the right measures, maximum coverage can be achieved with a minimum of resources. From events aiming for transfer of knowledge to campaigns for a large-scale spreading of quantum theory, the Quantenkoffer supports every conceivable form of public sensitization.

Social added-value

The Quantenkoffer is therefore not just another training instrument, but a step towards disseminating the findings of quantum physics to the public sphere - with the positive consequences of a scientifically thinking society, more awareness for mankind, nature and our existence in the universe.

Our vision is to keep the quantum revolution running. That the findings of more than 100 years of quantum physics become part of social debates and the engagement with physical phenomena finds a way into culture and entertainment. The key is *"grasping"* and *"experiencing"* quantum physics. And the Quantenkoffer ensures that everyone get the chance to do it.

In a nutshell

- *The basic principles of quantum physics should be made accessible to the entire society.*
- *Quantenmobiles bring fascination to schools, universities and public sphere.*
- *Training centers enable the deeper and long-term study of quantum physics.*
- *Rental systems allow the use in classrooms, in companies in seminar practical work.*
- *Information campaigns provide for a positive image of quantum physics among the public.*

Physics and Philosophy

The qutools interview with the unknown hobby philosopher Björn Habrich from Darmstadt.

Metaphysics and Enlightenment

Mr. Habrich, what is the relationship between physics and philosophy from your point of view?

Unfortunately, this relationship, along with the word metaphysics, got lost within the Enlightenment. The emergence of quantum theory has made physicists reflect on philosophical questions once more, which however did not really make it to the philosophers.

What within the Enlightenment led to this split?

In Newton's absolutely deterministic worldview, basically everything is calculable. Therefore, there is no more room left for philosophical questions about the heart of the matter. That is why I often plead for the metaphorical "removal of the Newtonian condom of determinism". I prefer "unprotected thinking".

Mindful Decoherence

New physical worldviews often draw social change after themselves. What influence does quantum physics have on our life together?

Unfortunately, none so far!

... and which one will it hopefully have?

Mindful decoherence! This expression unites philosophy and physics: decoherence is a term from quantum physics that describes the line between the unlimited freedom of thought and determinism usable in reality. This shift is smooth, but usually irreversible. Being aware of the reality of this decoherence leads to an increased mindfulness in dealing with it.

Social Influence

Does an understanding of quantum physics help improve our coexistence?

Yes, of course!

Of most concern to me is the acceptance of true coincidence. The acceptance that "orbital equations" are affected by a probability that increases with the size of the object, but for some things it does not reach 100%.

The implied assumption of being able to calculate everything leads to an arrogance in dealing with each other and with nature. I call that "two-faced determinism".

„Watch your thoughts,
for they become words.

Watch your words,
for they become deeds.

Watch your deeds,
for they become habits.

Watch your habits,
for they become your character.

Watch your character,
for it becomes your destiny."

Talmud

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