Max Planck Institute of Quantum Optics

MPQ

In the Light of Insight

New phenomena in the interaction between light and matter

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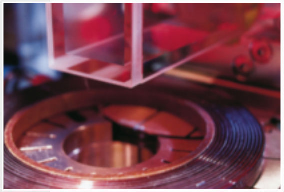
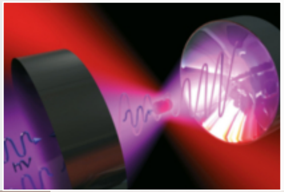
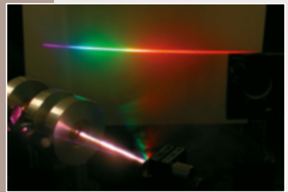
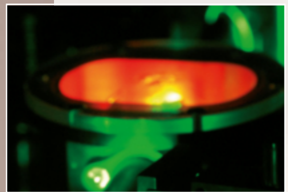
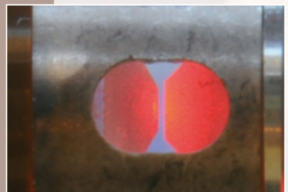










In the beginning there was light.

In the late 19th century it was proved beyond doubt that light propagates through space as an electromagnetic wave. Yet no sooner had the nature of this ‘flying‘ medium apparently been understood, than it revealed a whole new side to physicists: from experimental observations, first Max Planck (1900) and then a few years later Albert Einstein (1905) concluded that under certain conditions light behaves like a shower of particles – light quanta or ‘photons‘.

The discovery of the quantum nature of light marked the beginning of the **quantum revolution**. Initially proposed in an audacious thesis by Louis de Broglie (1924), experiments soon proved that this wave-particle duality applies to all fundamental building blocks of matter, including electrons and atoms.

The wave-like and particle-like properties of a quantum object belong together and fit like the two sides of a coin – they are said to be *complementary*. The consequences of this duality are formulated by the theory of quantum mechanics. According to this theory, two complementary quantities, such as the position and the momentum of a quantum particle, cannot simultaneously be measured precisely but only within a limited accuracy defined by the *Heisenberg uncertainty relation*. Moreover, quantum particles are found to be in a superposition of several quantum states, and their future behaviour can no longer be predicted with certainty but only with a probability defined by quantum mechanics.

These principles represent a break with classical deterministic mechanics, which clearly no longer applies in the realm of quantum particles, the microcosm. Yet quantum mechanics has proved to be an extraordinarily successful theory. It explains the structures of atoms and their spectra and describes how electrons orbit the nucleus of an atom. It was the understanding of quantum-mechanical principles which led among other things to the development of lasers.

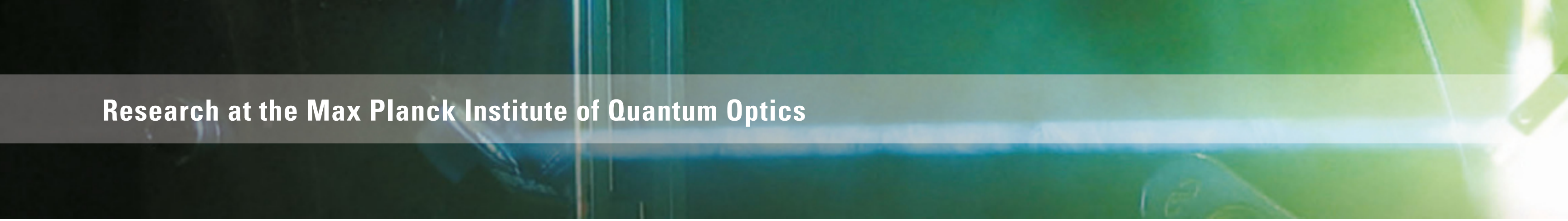
The paradoxical world of quantum particles

When applied to large ensembles of quantum particles, the laws of quantum mechanics lead to statistical predictions which are entirely consistent with our day-to-day experiences. On the other hand, the propagation of very thin beams of electrons and photons, with the particles passing through the slits one at a time, yields strange results: after a short while an interference pattern emerges on the screen, as if the particles had agreed upon their individual paths.

Yet the scenarios which ultimately arise for the behaviour of an individual particle are downright paradoxical and seemingly in conflict with reality. Does the uncertainty principle mean for example that an electron can pass through two slits simultaneously? In the search for answers to such questions, scientists developed 'thought experiments', some with the aim of refuting quantum theory on the grounds of its paradoxical consequences or to demonstrate its incompleteness.

Over the last 20 years, techniques for isolating, observing and manipulating individual quantum particles have been developed and refined. Scientists are describing the fact that these experiments have confirmed the unusual behaviour of quantum particles as predicted by theory as the **second quantum revolution**. For instance, two quantum particles, e.g. two photons emitted from a single atom, can be in an entangled quantum state. Their properties are then strongly correlated, independent of the distance between them. This non-local (dubbed by Albert Einstein) 'spooky' action at a distance is of great importance for quantum information processing and one precondition for the 'teleportation' of quantum states.

Exploring and making use of the bizarre properties of quantum particles are now among the most important areas of experimental and theoretical **quantum optics**. In the context of this basic research, novel measuring instruments and light sources are being developed, which are already being put to practical use in many fields.



Research at the cutting edge – Research for society

From quantum computers to medical X-ray equipment

Light plays a key role in the research carried out at the MPQ, both for the deeper understanding of quantum matter and for the development of novel concepts, measuring techniques and light sources which have consequences for many applications – from communication to the latest diagnostic equipment.

Quantum particles under control

One area of focus is the control of quantum matter. Scientists are now able to capture individual atoms or molecules using laser light or electromagnetic fields and to let them interact with individual photons. In doing so they are steadily approaching the limit set by the Heisenberg uncertainty relation.

These isolated particles might be used as quantum bits in future quantum computers. Whereas a classical bit can represent either state 1 or state 0 a quantum bit can be in all possible superpositions of two states – e.g. two different electronic or polarisation states – at the same time. A quantum computer built from a network of these quantum bits would process all superpositions in parallel, solving certain problems far more efficiently than a traditional computer. Over long distances these quantum bits could communicate via individual light quanta. The methods necessary for this make it also possible to encrypt data in a secure way. In this context theorists are developing new algorithms and concepts, which are making an important contribution to a theory of information based on quantum mechanics.

In other experiments, quantum gases are being cooled to extremely low temperatures close to absolute zero. The wave-like properties

of the particles are increasingly pronounced at such temperatures, leading to multifaceted correlations within the many-body system and ultimately to the emergence of new states of matter. The questions brought up by these experiments are being investigated in theoretical terms too, deepening our understanding of the collective behaviour of interacting quantum particles, which is responsible among other things for the electrical and magnetic properties of solids. This research could lead to the design of ‘tailor-made‘ materials.

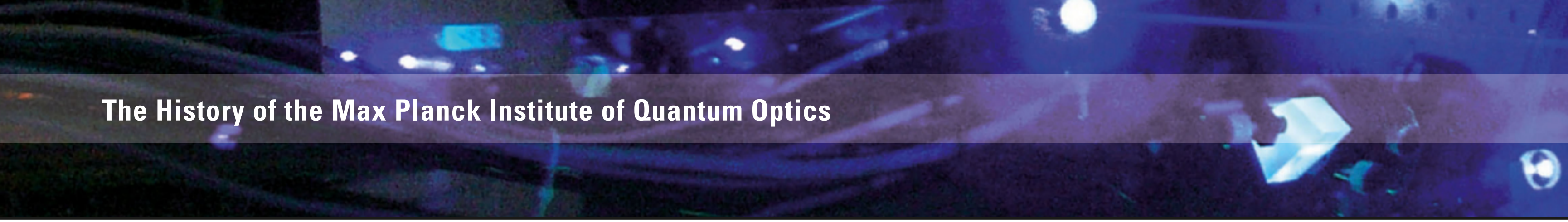
Novel tools in photonics

MPQ scientists are conducting pioneering work in the development of new types of light sources and measuring instruments, which are not only important for basic research but also have wide-ranging potential applications.

For instance, the Nobel Prize-winning frequency comb – a ‘light ruler‘ made of up to several millions of equidistant spectral lines – was originally developed for testing fundamental laws of physics using the high-precision spectroscopy of hydrogen. Its use has since been extended to applications as diverse as metrology (where it has set completely new standards), the construction of precision atomic clocks and trace gas analysis.

Complete control of the oscillation of light is also being achieved in experiments with high-intensity lasers. The focus of this work is the observation and control of electrons, which play a vital role in many fundamental processes – in atoms, molecules, solids and electronic components. Their motion can be ‘filmed‘ directly using light flashes of attosecond duration (1 as = 10^{-18} s), which are generated in sophisticated laser systems. This work is opening up the possibility of the direct observation of quantum-mechanical processes for the first time.

High-intensity laser pulses consisting of just a few oscillations with a perfectly controlled, ‘tailor-made‘ waveform can directly control the electrons in complex molecules, influencing chemical reactions for example. In other laser systems, high-intensity light pulses rip the electrons out of atoms in a hot gas and accelerate them to almost the speed of light. This work is leading to ultrahigh-quality X-ray sources and to compact, laser-driven particle sources, which among other things could improve the diagnosis and treatment of cancer.



The invention of the laser in 1960 gave scientists a tool that delivered a brand new quality of radiation:

Strongly collimated, monochromatic and above all coherent light. In the early 1970s two researchers at the Max Planck Institute of Plasma Physics (IPP) – Professor Karl-Ludwig Kompa and Dr. Siegbert Witkowski – also recognised the great potential of this new source of light and applied to the German Ministry of Research and Technology to set up a 'Laser Research Group' at the IPP. The group was duly founded in 1976. The third moving force behind this initiative was Professor Herbert Walther, who in 1976 was appointed as both Chair of Experimental Physics at the Ludwig-Maximilians-Universität (LMU) München and Max Planck Director.

From the outset the Laser Research Group, which became the Max Planck Institute of Quantum Optics in 1981, followed a twin path. On the one hand work focused on the development of high-power lasers, culminating in 1986 in the operational start of the photochemical iodine laser, Asterix.

On the other hand the use of laser light for research into the quantum world gained increasing significance. While Professor Kompa investigated the reaction dynamics of complex molecules with laser pulses of femtosecond duration, Professor Walther experimented with individual atoms and ions, studying their interaction with individual light quanta. His work paved the way, for example, for the development of high-precision atomic clocks.

The many facets of quantum optics are also reflected in the research programme being presently pursued at the MPQ. Professor Theodor W. Hänsch´s Laser Spectroscopy Division, for example, founded in 1986, is involved on the one hand in verifying natural constants with the aid of high-precision spectroscopy. On the other hand the frequency comb, developed in this context, and for which Professor Hänsch won the Nobel Prize in Physics in 2005, is used worldwide as a tool in laser development. This division also investigates the behaviour of extremely cold quantum matter.

Quantum physics is also at the heart of research in the Divisions of Quantum Dynamics (founded in 1999 by Professor Gerhard Rempe), Theory (founded in 2001 by Professor Ignacio Cirac) and Quantum Many Body Systems (founded in 2008 by Professor Immanuel Bloch). Scientists here are engaged in the steering and control of individual atoms and their interaction with individual photons, and in the manipulation of dilute, extremely cold quantum gases. The Theory Division in particular investigates the possibility of processing and communicating quantum information.

The area of laser development is pursued today mainly in the Attosecond Physics Division, founded in 2003 by Professor Ferenc Krausz. His laser systems deliver ultrashort pulses with a power of up to 100 terawatts. A petawatt laser, which aims to achieve ten times this power, is under development. The research conducted by Professor Krausz also has a close connection to the quantum world, as the ultrashort light pulses generated in his division enable the direct observation of quantum mechanical states and transitions. At the same time the high-power lasers are used in the development of new radiation and particle sources for applications in medicine and industry.

Above: Aerial photograph of the Max Planck Institute of Quantum Optics.
Below: Aerial photograph of the research site Garching. The MPQ is located in the south. It can be made out at the bottom left.
Photographs: Artur Gerngross, FOTAG

The Five Scientific Divisions

The Max Planck Institute of Quantum Optics is organised into five scientific divisions. Each division is headed by a Director appointed by the Max Planck Society.

The directors at the Max Planck Institutes are entirely free to choose their research areas and select their teams themselves. This long-standing tradition, which is distinct from that found in many other research organisations, was begun by Adolf von Harnack, the first president of the forerunner to the Max Planck Society, the Kaiser-Wilhelm-Gesellschaft (founded in 1911).

The Max Planck Institutes attract world-class, independent-minded scientists.

Quantum Many Body Systems

Professor Immanuel Bloch

born 16 November 1972 in Fulda (Germany)

Degree in physics from the Rheinische Friedrich - Wilhelms - Universität Bonn, *Dr. rer. nat.* under Professor Hänsch at the LMU Munich, Chair of Experimental Physics at the Johannes Gutenberg-Universität Mainz, since August 2008 Director at the MPQ, since May 2009 Chair of Experimental Physics – Quantum Optics at the LMU.

Photo: Philip Morris Stiftung

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Theory

Professor Ignacio Cirac

born 11 October 1965 in Manresa (Spain)

Degree in physics and *Doctor en Ciencias Físicas* from the Universidad Complutense de Madrid, Professor Titular at the University of Castilla-La Mancha, Professor at the Institute of Theoretical Physics at the University of Innsbruck, since 2001 Director at the MPQ, since 2002 Honorary Professor at the Technische Universität München (TUM).

Photo: Thorsten Naeser, MPQ

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Laser Spectroscopy

Professor Theodor W. Hänsch

born 30 October 1941 in Heidelberg (Germany)

Degree in physics and *Dr. rer. nat.* from Ruprecht-Karls-Universität Heidelberg, Assistant Professorship at Ruprecht - Karls - Universität Heidelberg, Professor of Physics at Stanford University (USA), since 1986 Director at the MPQ and Chair of Experimental Physics – Laser Spectroscopy at the LMU Munich.

Photo: BMW AG

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Attosecond Physics

Professor Ferenc Krausz

born 17 May 1962 in Mor (Hungary)

Degree in electrical engineering from Budapest University of Technology, *Dr. techn.* and *Dr. techn. habil.* at the Vienna University of Technology, Professor in the Department of Electrical Engineering at the Vienna University of Technology, since 2003 Director at the MPQ, since 2004 Chair of Experimental Physics – Laser Physics at the LMU Munich.

Photo: Thorsten Naeser, MPQ

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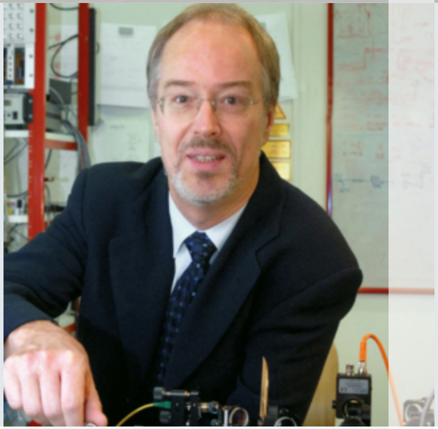
Quantum Dynamics



Professor Gerhard Rempe

born 22 April 1956 in Bottrop (Germany)

Studied physics and mathematics at the Universität Essen, degree in physics from LMU Munich, *Dr. rer. nat.* and *Dr. rer. nat. habil.* at the LMU, Millikan-Fellow at the California Institute of Technology (USA), Professor of Physics at the University of Konstanz, since 1999 Director at the MPQ and Honorary Professor at the Technische Universität München (TUM).

Photo: Thorsten Naeser, MPQ

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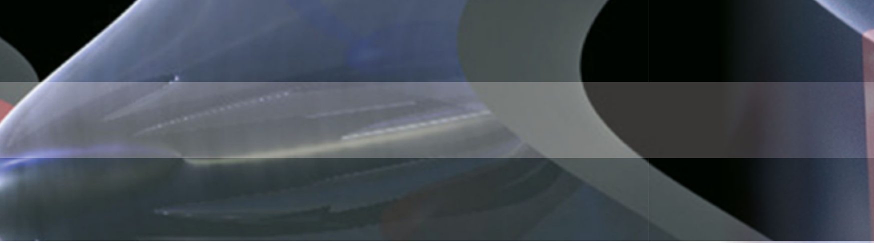
Understanding the interactions in quantum many-body systems and exploiting these for quantum-information purposes

present some of the most outstanding challenges in quantum physics today. Research in the Quantum Many Body Systems Division focuses on realizing and controlling such systems using ultracold atomic and molecular quantum gases.

Quantum gases as models for condensed matter systems, novel quantum-information processors and set-ups for precision spectroscopy

Scientists in this division experiment with ultracold quantum gases of bosons or fermions held in optical and magnetic traps. In several experiments controlled periodic potentials trap these atoms or molecules in a crystal lattice of light. In such microscopic arrays, quantum gases can serve as versatile model systems for condensed-matter physics, or as quantum-information processors. Every one of the hundreds of thousands of atoms in the optical lattice has to be controlled at the limits of quantum mechanics and the interactions between the particles have to be carefully adjusted.

In this way it is possible to realize quantum phases that have previously only been predicted by theory and whose generation in real materials is almost impossible. Furthermore, it is possible to study the collective dynamic behaviour of the particles and in this way to investigate the emergence of fundamental quantum correlations which determine the characteristics of the entire system. Ultracold quantum gases can therefore be used to address, for example, fundamental questions related to superconductivity, superfluidity and



quantum magnetism in many-body systems – aspects that are of interest to basic research and a range of applications.

In addition, ultracold atoms and molecules in optical lattices are an excellent tool for carrying out precision measurements in atomic and molecular physics, enabling, for example, chemical reactions to be controlled on the quantum scale and the generation of molecules in precisely defined quantum states in which all degrees of freedom are perfectly controlled.

Novel matter-light interfaces

The Quantum Many Body Systems Division also investigates techniques for developing novel interfaces between these many-body systems and light in order, for example, to generate novel quantum memories for light which are critical for communication between quantum systems. In addition atomic many-body systems form novel light sources for non-classical radiation in which the high degree of control over the atoms can be exploited to generate complex quantum states of light.

Vacuum chamber with a magnetic trap in which ultracold quantum gases are produced. Photo: Philip Morris Stiftung

The quantum world of atoms, molecules, and photons is plagued by strange and paradoxical phenomena that challenge all our intuitions.

For example, these microscopic particles can tunnel through classically forbidden regions, behave as if they were in several places at the same time, or develop strange correlations even if they are separated by a long distance and no physical action is interchanged between them.

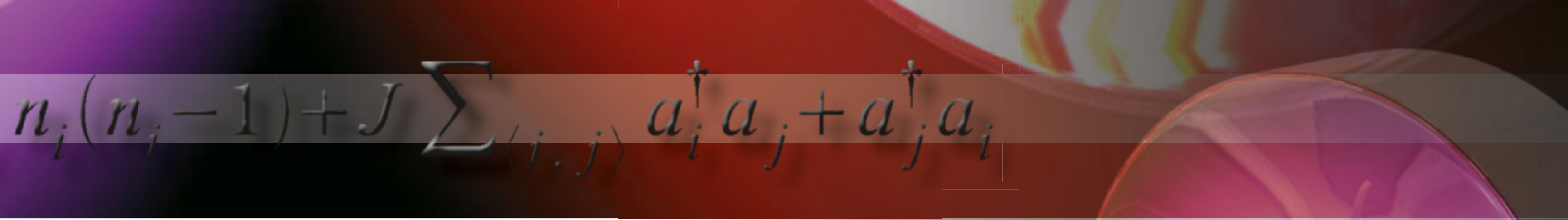
None of these phenomena exist in our macroscopic world but they are routinely observed nowadays in many laboratories that deal with microscopic objects. In fact, control and manipulation of these objects would make it possible to construct devices that could perform otherwise impossible tasks.

A new era of information technology

In particular, a new information era would emerge since the new methods of processing and transmitting information would have very little in common with conventional computing. One step in this direction is to investigate new ways of controlling the world of atoms, molecules, and photons.

Quantum computers based on trapped ions or neutral atoms, as well as quantum repeaters that utilize photons emitted and absorbed by atoms in cavities or atomic ensembles at room temperature, are examples of proposals born in the Theory Division in collaboration with other international partners.

The group of Professor Cirac has also introduced the possibility of performing quantum simulations by means of atoms in optical lattices, or ions in different trap set-up.

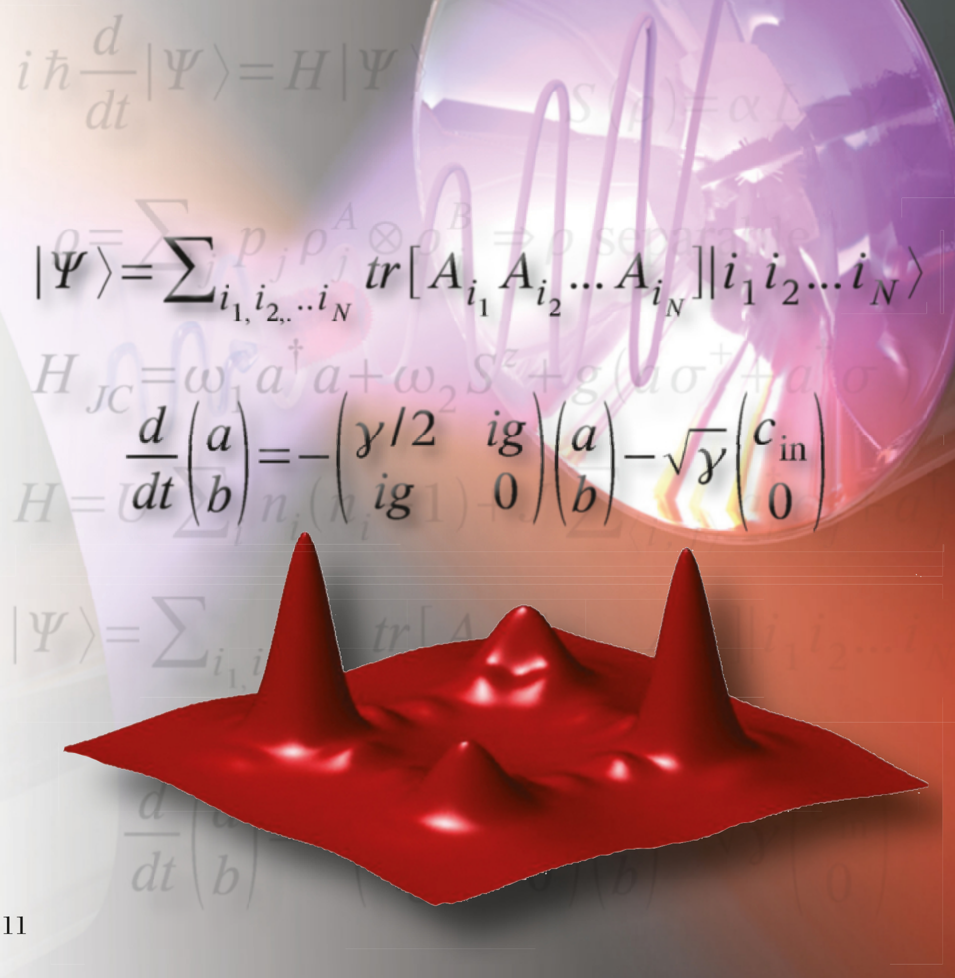


Quantum mechanical tools and methods

At the same time the Theory Division investigates how to exploit the quantum mechanical behaviour of particles in order to process and transmit information in more efficient and secure ways. In this context new theoretical tools are created to characterize and quantify entanglement, an intriguing property of quantum mechanics which is responsible for most of its fascinating phenomena and applications. These techniques are also used to develop sophisticated methods for describing many-body quantum systems in completely new ways.

Not only have these methods given rise to very powerful numerical algorithms for studying quantum systems, they have also found application in other branches of physics.

With all these activities the Theory Division participates in the creation of a new theory of information based on quantum mechanics.



The interaction of light with atomic matter opens a fascinating window into the microscopic quantum world.

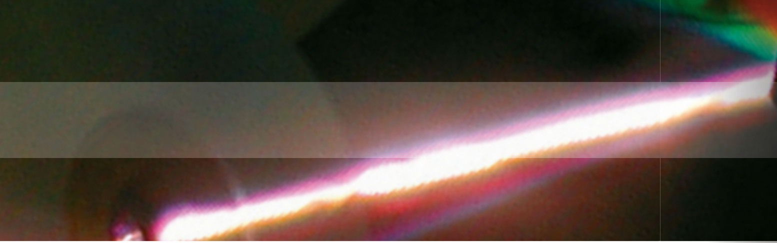
Are fundamental constants really constant? Are there detectable differences between matter and antimatter? How well can quantum mechanics describe simple hydrogen-like atoms and ions? Are there limits to the possible accuracy of optical atomic clocks? Can we build an X-ray atomic clock? How far can precise laser spectroscopy of cold trapped ions be extended into the extreme ultraviolet?

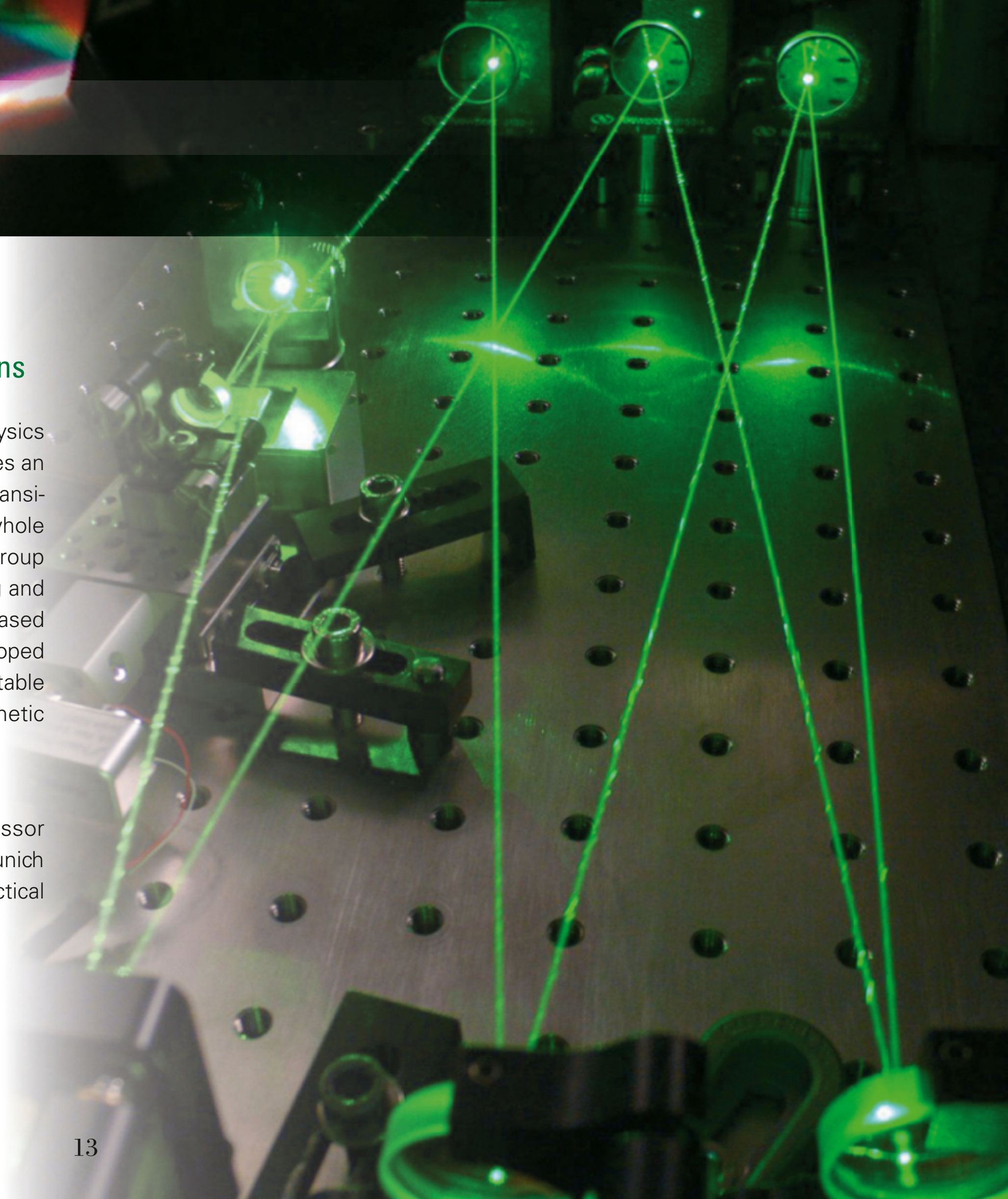
Can experiments with ultracold atomic bosons and fermions lead to unexpected novel states of correlated quantum matter? What can we do with a quantum laboratory on a micro-fabricated atom chip? These are just some of the questions explored by the Laser Spectroscopy Division.

Laser spectroscopy – a window into the microscopic quantum world

One focus of research is precise laser spectroscopy of simple atomic systems such as hydrogen. It touches upon the foundations of physics because it reveals information about the fundamental constants of nature and the possible limits of present theories of physics. The development of the optical frequency comb technique – for which Professor Theodor W. Hänsch received the Nobel Prize in Physics in 2005 – improved the precision of frequency measurements in the optical range by a factor of 10^4.

This instrument is now a standard tool in laser spectroscopy and metrology. It is the key to the development of atomic clocks of unprecedented precision, and is set to find application in more and more areas, from space research and astrophysics to medical trace gas analysis.





Ultracold matter, atom chips and entangled photons

The Laser Spectroscopy Division also works on the quantum physics of ultracold atomic gases. For example, at very low temperatures an ensemble of around one million atoms can undergo a phase transition to a Bose-Einstein condensate (BEC), a state in which the whole ensemble behaves like one single coherent wave. In 1999 a group of Professor Hänsch became the first to succeed in generating and manipulating such a BEC on a microchip. For instance, a chip-based atomic clock, suitable for portable use, has already been developed using this technology. These devices are also of interest as portable precision sensors for measuring extremely weak electromagnetic fields or slight changes in gravitational force.

The affiliated experimental quantum physics group of Professor Harald Weinfurter at the Ludwig Maximilian's University of Munich is exploring novel systems of entangled photons and their practical applications, for example quantum cryptography.

Enhancement cavities increase the sensitivity of spectroscopy experiments and can be useful for the generation of frequency combs in the extreme ultraviolet (XUV).
Photo: Birgitta Bernhardt, MPQ

The interaction between light and electrons is at the heart of research in the Laboratory for Attosecond Physics.

Deep in the microcosm time dimensions are extremely short. Electron motion in atoms and molecules is measured in attoseconds. One attosecond is a billionth of a billionth of a second (10^{-18} seconds). If you want to observe electron motion, you need a tool that is equally fast. By generating pulses of laser light lasting only a few attoseconds physicists of the Laboratory for Attosecond Physics (LAP) are able to visualise this motion.

Electrons are of elementary significance. They bind atoms into molecules. They bring about chemical reactions and structural changes in molecules and as a result initiate fundamental biological processes, including those involved in the origin of disease. Electrons also play a central role in transmitting information and stimuli. Information technology makes use of electrons to process and transmit data. Using the shortest light pulses in the world LAP scientists can open up the cosmos of electrons, and use their findings to promote technological progress and gain a better understanding of the fundamental processes of nature.

As with conventional photography, the shorter the pulses of light, the sharper the images of the microcosm. With their attosecond X-ray pulses LAP scientists have made it possible for the first time to visualise electron motion within atoms and molecules. The controlled electrical field of visible laser light gives them increasing control over this motion.

High-intensity laser pulses

The LAP team also works with high-intensity laser pulses lasting only a few femtoseconds (10^{-15} seconds). In this time it is possible to equip a light pulse with a power equivalent to that generated by all the

nuclear power stations in the world. These pulses of light can set electrons free from atoms and accelerate them to almost the speed of light. Following this the particles are accelerated back and forth in a small undulator and they emit X-rays. The LAP team has been able to demonstrate that this technology has the potential to produce so-called brilliant X-rays, something that at present can only be achieved by means of expensive accelerators of several kilometres in length. Laser-driven X-rays will deliver a new image quality for biological and medical applications and help visualise even the tiniest structures.

Light for the future

As well as expanding our understanding of the fundamentals of life, research into electron phenomena will help us develop innovative new technologies for medical applications, for example in the diagnosis and therapy of diseases, including some that are at present regarded as incurable. Attosecond physics opens the way for accelerating information processing to its ultimate limits. Calculations could be performed with the frequency of light oscillations. That would be millions of times faster than the capabilities of today´s electronics.

LAP scientists setting up a beam line to generate attosecond pulses.
Photo: Thorsten Naeser, MPQ

The world of quantum physics continues to amaze and fascinate, one century after its discovery.

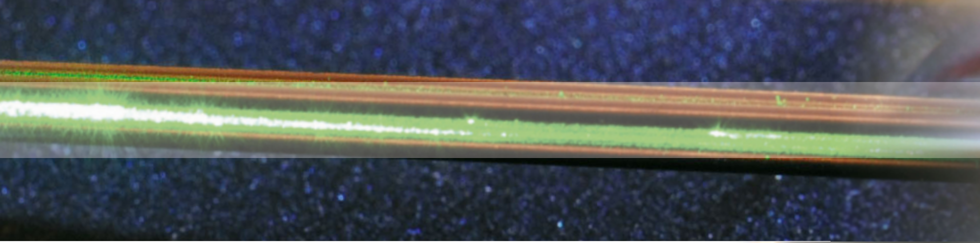
What is the difference between the quantum world and the classical world of our everyday experience? Is it the often mentioned wave-particle duality, or maybe Heisenberg's uncertainty relation? Not exactly, since the underlying concepts are borrowed from classical physics.

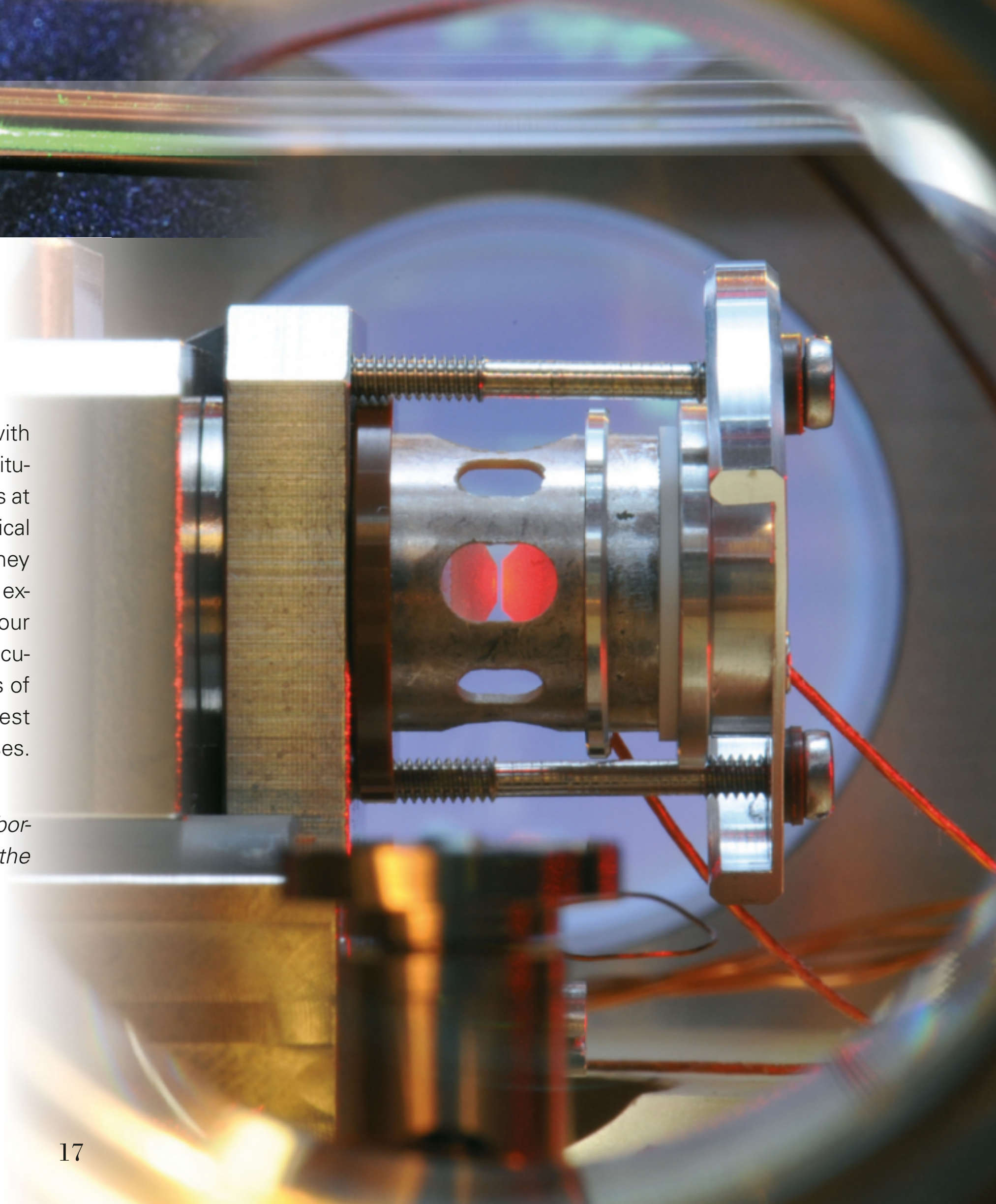
The crucial difference is rather the fact that in quantum systems the particles can be interlaced much more tightly than is allowed by classical physics. In view of this entanglement the notion of information or interaction – dubbed by Einstein as 'spooky action at a distance' – gains a completely new meaning.

Interfaces to the quantum world

A focal point of the Quantum Dynamics Division is the investigation of fundamental phenomena in the quantum world and their applications for the processing of information. In this context interfaces between the classical world and the quantum world are being developed. 'Workhorses' are individually addressable atoms in optical resonators of the highest possible quality.

This allows us to build novel light sources which at the push of a button emit a bit stream of single or entangled photons. The single atoms can also be used as an optically non-linear medium for the coupling of two single photons. The goal of this research is to connect the atoms by means of tailor-made photons forming a quantum network and ultimately a quantum internet. By successively adding more atoms such a quantum system can be stepwise enlarged.





Cold quantum gases as gigantic matter waves

Complementary to these experiments is the strategy to start with a large system and improve the control over the individual constituents. On the one hand, this work is performed with quantum gases at temperatures close to absolute zero. Such gases differ from classical gases in that all the atoms together form a gigantic matter wave. They are ideally suited to perform quantum simulations and in this way explore open questions in many-body physics, such as the behaviour of electrons in solid-state crystals. On the other hand, polar molecular gases like water vapour are ideal for investigating new classes of chemical reactions at temperatures below one Kelvin. The biggest challenge here is to invent methods for the cooling of molecular gases.

"Experiencing the beauty and diversity of quantum physics in laboratory experiments and developing the quantum technology of the future is a most rewarding experience." Gerhard Rempe

Above: 'Rails' for guiding cold molecules.
Right: Pair of mirrors (red) for experiments with single atoms and single photons (threefold magnification).
Photos: Christian Sames, MPQ

The research groups at the Max Planck Institute of Quantum Optics work in close cooperation with universities and other institutions in Germany and around the world.

Independent research groups

A number of independent research groups have been embedded in the five scientific divisions at the institute since 2004. Thanks to third-party funding – for example from the Max Planck Society, the Deutsche Forschungsgemeinschaft (DFG), Minerva and the European Research Council (ERC) – the leaders of these groups have the opportunity of carrying out their own independent research projects, working on them together with their own doctoral and diploma students, for a period of around five years.

Their topics are an excellent contribution to the MPQ research programmes as can be seen by developments such as chip-based frequency combs, ion crystals serving as quantum simulators, experiments with antimatter as well as new methods of attosecond spectroscopy and metrology.

At the MPQ this structure has proved to be highly successful, as on average after around two years, the group leaders are offered professorships at other research institutions in Germany or abroad.

National projects

The MPQ is involved in a number of national cooperations and joint projects with other universities and research institutes, for example projects funded by the Deutsche Forschungsgemeinschaft (DFG), projects conducted in cooperation with the Fraunhofer Gesellschaft and projects financed by the Federal Ministry of Education and Research. A special role is played here by the Clusters of Excellence, each spanning several research institutions. The MPQ is involved in two of the clusters launched by the DFG in October 2006:

At the Munich-Centre for Advanced Photonics (MAP) researchers are working on the development of new coherent light sources and laser-based particle sources. These new tools will make it possible to measure inner-atomic processes with enormous spatial and temporal precision and to explain the structure of complex molecules.

At the Nanosystems Initiative Munich (NIM) the aim is to develop a range of novel nano-scale systems which can then find application in

a range of areas such as information technology and life sciences, or even in a combination of both disciplines.

International links and cooperations

The MPQ is engaged in constant dialogue with institutions and researchers around the world. As no less than 60 guest scientists come from around 40 different countries in and outside Europe, the working groups at MPQ are inherently international in character.

Many projects at the MPQ are supported by the European Union. Of special importance is the participation of the MPQ in the major European research initiatives Extreme Light Infrastructure (ELI), Laserlab Europe, Scalable Quantum Computing with Light and Atoms (SCALA), and its successor Atomic Quantum Technologies (AQUTE). Important cooperation projects are also maintained with universities from Israel, Japan and Saudi Arabia.

Photo: Dr. Olivia Meyer-Streng, MPQ

Employees in many areas at the MPQ make their contributions to the outstanding research results.

Education and training

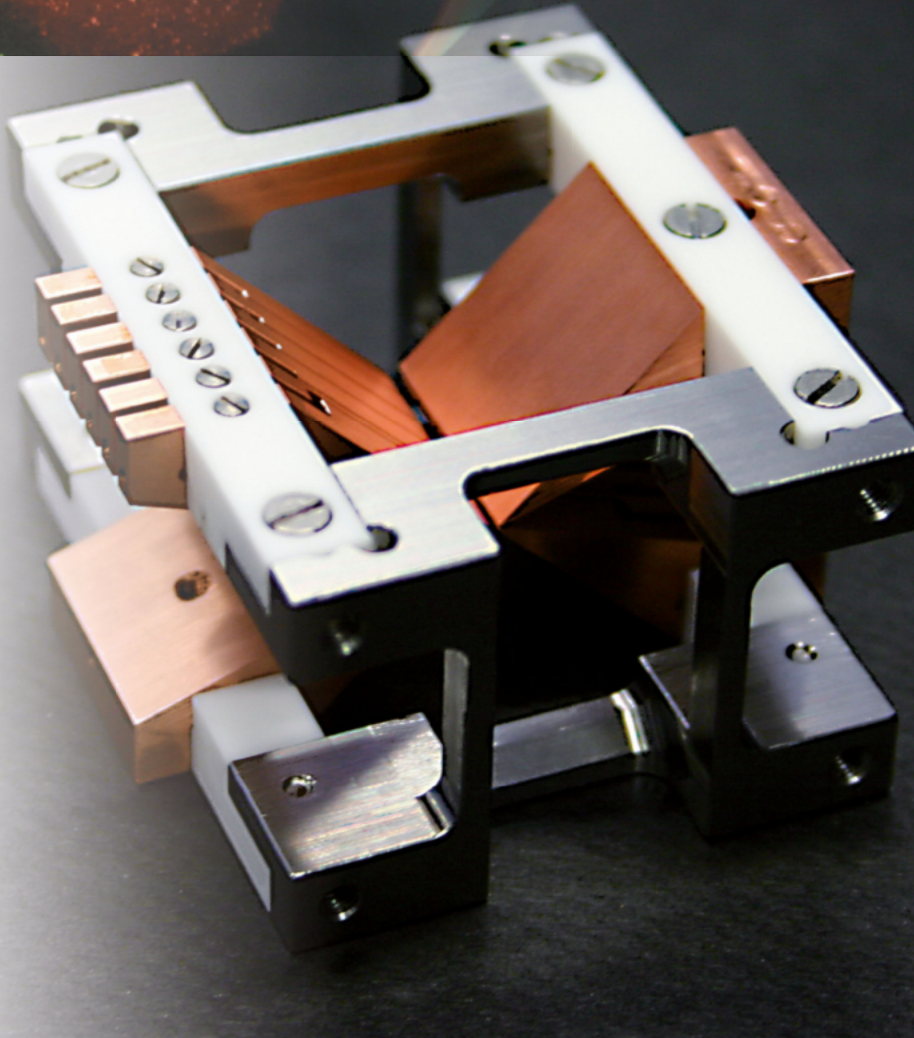
Around 150 doctoral and diploma students are actively involved in the research work in the divisions and the research groups at the MPQ. This brings benefits to both sides: As all the directors of the divisions are affiliated to the universities in Munich through professorships, students have access to a broad spectrum of education. The academic qualifications awarded to successful candidates are conferred either by the Ludwig-Maximilians-Universität München (LMU) or the Technische Universität München (TUM), depending on the affiliation of the director they were working with.

The two doctorate programmes at the MPQ have great appeal to students from abroad: the International Programme of Excellence on Quantum Computing, Control and Communication (QCCC) with a focus on quantum information processing and neighbouring fields and the International Max Planck Research School on Advanced Photon Science (IMPRS-APS), concerned with the development of new kinds of light sources and their application in physics, chemistry and biology.

Machine shop and support services

A key part in the laboratory experiments is played by the employees in the machine shop, who design and manufacture important components using state-of-the-art techniques. In the scientific divisions, too, technicians are closely involved in the experimental work, helping for example to set up large-scale laser systems or manufacture mirrors of the very highest quality in clean rooms and laboratories for vapour deposition.

A range of other support services also assists the scientists, freeing them to devote maximum time to their research: the IT Service, for example, provides the IT infrastructure essential for proper scientific operations. The Press & Public Relations Department keeps the media informed about the latest research results and important developments at the institute, while also looking after groups of visitors and arranging events such as the 'Open Day'.



The library catalogues the scientific publications and produces analyses of citations. It provides all the key scientific journals and specialist books and carries out literature research. The Regional EU-Office Bavaria of the Max Planck Society is also based at the MPQ. This office supports scientists in their applications for EU funding for research programmes and projects.

The administrative functions of sales, human resources and accounts look after employee contracts, purchasing of laboratory and technical equipment and bookkeeping. The facility management ensures all the basics are in place and in working order for laboratory operations: for example, electricity supplies, water circuits and the air-conditioning systems needed for the experiments.

A team of drivers helps the directors to meet their many commitments and moves sensitive experimental equipment safely to the labs. Finally, the people from the MPQ cafeteria provide a social environment and organise internal celebrations from time to time.

The device shown at the right is used by one of the independent research groups to trap and store ultracold ions for some period of time. This particle trap has been built by the machine shop, taking about 160 hours of work. External dimensions are 57x49x30 millimetres, with a manufacturing tolerance of around a hundredth of a millimetre. Photo: Uwe Langenegger, MPQ

The number of people working at the Max Planck Institute of Quantum Optics has grown enormously in recent years.

In 1976 just 50 people were working at the MPQ. By 1999 it was around 150, but today, the figure has expanded to almost 400. Three-quarters of them are scientists, among them at any one time an average of 60 guest scientists, each of them researching at the MPQ for a few months. Doctoral and diploma students account for around 150 of the total.
The number of publications and awards has also increased enormously.

Prizes and publications

Each year the MPQ publishes an average of 180 research papers in scientific journals, a considerable number of which (around 30) in renowned journals such as Nature and Science.

Prizes and awards are conferred virtually every month on scientists at the MPQ. An outstanding highlight was the Nobel Prize in Physics, awarded to Professor Theodor W. Hänsch in 2005.

The institute buildings

The institute premises are on the southern edge of the research campus at Garching, on an approximately 57,000 m^2 site. In 1986, when the institute moved into these premises, the offices, laboratories and workshop extended over 6,600 m^2 of space.

With the addition of a southern wing in 2001 the total space available expanded to almost 9,300 m^2. Because of the rapid rise in the number of people working at the institute, plans are underway to expand capacity to 12,000 m^2.

Information for visitors

Would you like to visit the Max Planck Institute of Quantum Optics, have a look at our laboratories and talk to scientists about their research? If so, please feel free to contact us. We are happy to organise tours for groups of up to 30 people – delegations, school children, physics students and any interested lay persons.

Contact:
Dr. Olivia Meyer-Streng
Head of Press & Public Relations
Phone: 089 - 32905 213
e-mail: mpq-presse@mpq.mpg.de

The MPQ regularly organises an 'Open Day', and takes part in the annual Germany-wide 'Girls' Day'.

For further information on upcoming events, go to our website:
www.mpq.mpg.de

Groundbreaking research results of the scientific divisions on the title pages of renowned scientific journals.

Postal address

Max-Planck-Institut für Quantenoptik
Hans-Kopfermann-Strasse 1
D-85748 Garching bei München
Germany

Directions

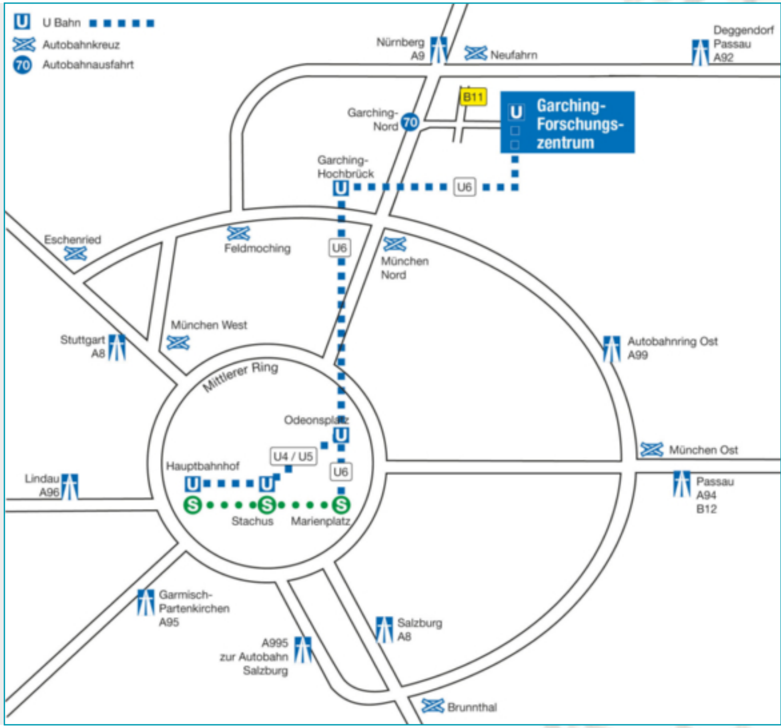
By car:

From the A9 motorway take the Garching-Nord exit, cross the B11 state road and then turn right at the second junction.

From the centre of Munich by public transport:

Take the U6 underground line to the stop called "Garching-Forschungs-zentrum". From there it´s about an 800-metre walk south (follow the signs).

For further information about the location of the MPQ and directions to it, go to our website: www.mpq.mpg.de



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