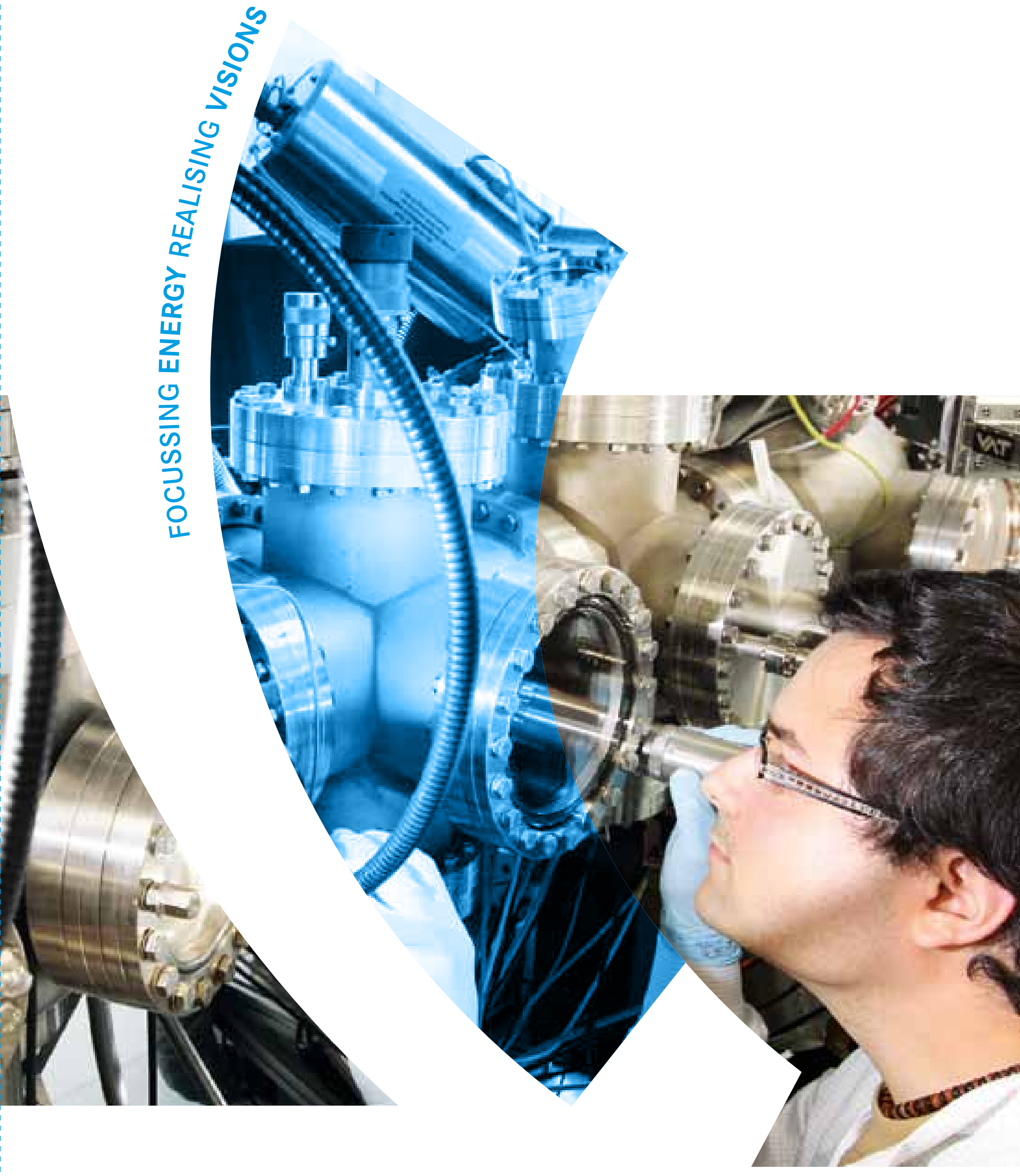
Helmholtz Zentrum Berlin

FOCUSSING ENERGY REALISING VISIONS



RESEARCH FOR THE ENERGY OF TOMORROW

Thin-film photovoltaics and solar fuels

Scientists check their experimental setup. HZB is a workplace not only for physicians but also for scientists from a variety of different fields.

HZB IN BRIEF

The Helmholtz-Zentrum Berlin (HZB) operates two scientific large scale facilities for investigating the structure and function of matter: the research reactor BER II for experiments with neutrons and the synchrotron radiation source BESSY II, producing particular X-rays known as photon beams. Another main research area is solar energy, which comprises seven institutes and divisions.

Fundamental research done by HZB scientists ensures that future generations of solar cells will become the market standard. This provides the basis for developing new materials for **thin-film solar cells** and for producing solar fuels. Thin-film technologies are developed up to a stage where industrial research ties in. As co-founder of the **Photovoltaic Competence Centre** (PVcomB), HZB helps to accelerate the transfer of new findings to industry and offers many activities to promote young scientists.

HZB was founded in January 2009 by merging the former Hahn-Meitner-Institute and the Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung (BESSY), two of Berlin's largest research centres. Due to the merger, HZB is now one of the few centres worldwide to offer the whole range of **instruments for neutron and synchrotron radiation** within one laboratory structure.

Facts and Figures

The HZB employs approximately 1,100 staff members, of whom 800 work at Wannsee and 300 at Adlershof. It has a total budget of about 110 million Euros. About 100 doctoral candidates from neighbouring universities are involved in research and training at the HZB. Beyond the Berlin-Brandenburg region, the HZB cooperates with more than 400 partners at national and international universities, research institutions and companies.

HARNESSING THE POWER OF THE SUN

Internationally renowned scientists, large scale facilities for unique analyses and an innovative environment – HZB is well positioned in solar energy research. Researchers at laboratories in Wannsee and Adlershof are already developing future generations of solar cells.

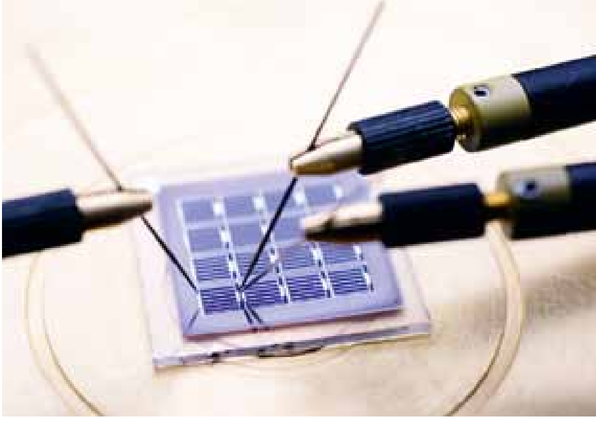
Roofs are loaded with solar cells, a solar module is resplendent above a parking metre – it seems as if photovoltaics, the technology to convert solar energy into electricity, is already omnipresent. Yet, in reality, only a tiny fraction of the available sunlight is being used to produce electricity or chemical fuels. The reasons for this are manifold. For example, yields of currently available solar cells are still too low. Moreover, production costs are enormously high, especially for systems with absorbers built out of rare and therefore expensive elements.

Photovoltaics: Clean and Efficient

Given our endeavours to protect the environment and a constantly growing need for energy, our supply of energy is one of the biggest challenges we will have to face in the near future – politically, economically, but also scientifically. With depleting fossil fuel reserves, calls for renewable energies continue to grow louder.

Experts agree that energy from the sun will considerably contribute to the energy mix of the future. Sustainably produced chemical fuels for aviation and heavy transport will join the main energy carrier, electricity. In order to harness the sun's full potential, HZB researchers are delving into scientific and technological basis of modern photovoltaics. **Continued solar energy research is essential and will secure Germany's international leadership in this technology.**

Thin layers generate electric current.



Our aim is to develop technologies to allow transformation of energy supplies to renewable energies. When and how this conversion will occur, is a political decision.

Prof. Dr. Dr. h.c. Wolfgang Eberhardt, Scientific Director for Energy Research of HZB

Most solar electricity systems still employ silicon wafers. Even though they are quite efficient, wafers are expensive and energy-intensive to produce at the same time. Thus, they will gradually be replaced by new thin-film solar cells, which feature extremely thin light-absorbing layers made from other materials in addition to silicon. The solar cell of the future is economical, mass-producible and at the same time highly efficient.

Solar energy researchers get closer to this noble objective day by day. They are currently puzzling over new absorber layers that capture the light more efficiently than before. They are replacing rare elements with more common ones and are taking a deep look inside solar cells using ultra-modern analytical methods such as the institute's own synchrotron BESSY II. They are also aiming at optimizing solar cell manufacturing processes.

Unique Methods

Solar energy research at HZB attracts international interest, especially because of the unique range of methods available to scientists. Located in one of Germany's most important solar cell production regions, the institute masters the balancing act between pure research and applied technological development.

(left) Thin-film solar cells can be properly integrated into roof architecture.

(right) Photovoltaics is becoming omnipresent.

CIS modules by Sulfurcell, an HZB spin-off, convert sunlight to electricity.

SILICON – ULTRA-THIN

To reduce the material costs of solar cells, HZB researchers are looking to apply ultra-thin layers of silicon onto glass. This is not as easy as it sounds. Silicon crystals namely grow on glass in a polycrystalline structure; that is as many tiny, individual grains. The trouble is, at every grain boundary in a solar cell, some charge carriers will be lost. Defects arise where the free charge carriers, responsible for transporting the current, scatter in all directions, creating a natural limit to the efficiency.

Glass as a low-cost substrate.

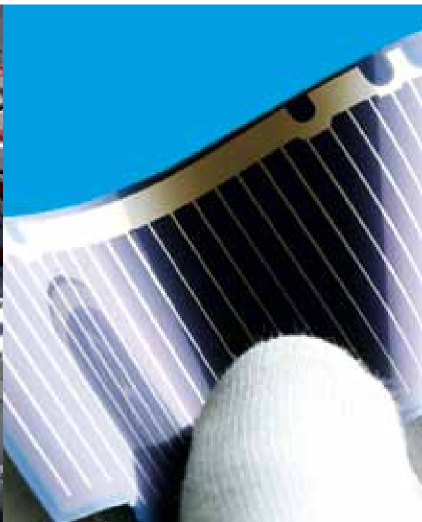
To get optimal crystal properties, one needs extremely high temperatures. Unfortunately, glass substrates cannot withstand such temperatures. Nevertheless, because glass is readily available everywhere in the world, making it highly cost-effective, HZB researchers are persisting with it. Using **electron beam evaporation**, a commonly used material coating method, they deposit silicon amorphously, i.e. in non-crystalline form, and then allow it to anneal at 600 degrees Celsius. Under these conditions, ordered crystals grow to a few microns in size. Hydrogen and extremely thin amorphous silicon layers are added to neutralize the remaining defects at the boundaries of these crystals.

The flow of current in a solar cell depends on more than just the crystalline properties of silicon. The incident light must also be optimally used. The new silicon layers are so thin that the crystals cannot fully capture the light, so, to address this, a window layer of light-collecting zinc oxide is added to make the final solar cell.

Quantum effects can also be exploited to further improve the efficiency of solar cells. Stacking different absorber materials widens the spectrum of useful light energy.

New solar cells arise in modern coating systems.

A flexible CIS solar cell on titanium foil.



NEW MATERIALS – FLEXIBLE AND EFFICIENT

Solar cells without silicon? A few years ago, many photovoltaic system manufacturers would have said this was a pipe dream. Now, modules made from alternative materials are already on the market. HZB researchers are taking them a step further.

Semiconductor materials can be excited by photons into conducting current, thus obtaining electricity from sunlight. Aside from silicon, there are copper compounds particularly suitable for this, called **chalcopyrites.** These can be deposited as extremely thin layers onto glass and even onto flexible foils. That saves materials and energy in their production. Solar modules made from chalcopyrites are already commercially available and achieve efficiencies comparable to multicrystalline silicon solar cell modules.

High efficiency in the laboratory

Solar energy researchers value above all the enormous variability of semiconductors. Chalcopyrites can be composed of different element groups in almost any combination. The most popular in photovoltaics are those made of **copper-indium-sulphide** and **copper-indium-gallium-selenide.** Such CI(G)S solar cells already achieve efficiencies of over 20 percent, in the laboratory at least.

Combined with innovative deposition methods and low-cost production, these innovative materials are the **basic building blocks for the next generation of solar cells.**

The Chalcopyrite Reference Line

HZB scientists need chalcopyrite cells of consistent quality for their research. To guarantee this, solar cells and small-scale modules are continuously produced on the institute’s own reference line. This allows them to study and improve individual process steps and parts of the production chain during actual production. If the tested methods prove sound, then the reference line will also be adapted to the latest findings. Furthermore, the results can be reliably transferred from the reference line to industrial production lines.

A sample is inserted into a coating system.

INTO THE FUTURE WITH NANOSTRUCTURES

Process-oriented materials research

Breakthroughs in chalcopyrite research form the basis of future solar cells. Yet, they are only of industrial interest if they can be applied on a large scale. Researchers are therefore refining the basic constituents of the cells and are developing new concepts and manufacturing processes to produce solar cells as economically as possible:
methods to grow cell layers controllably on substrates, for example, or nanostructured cells that use photonic effects produced by the motion of light particles on the smallest of scales.

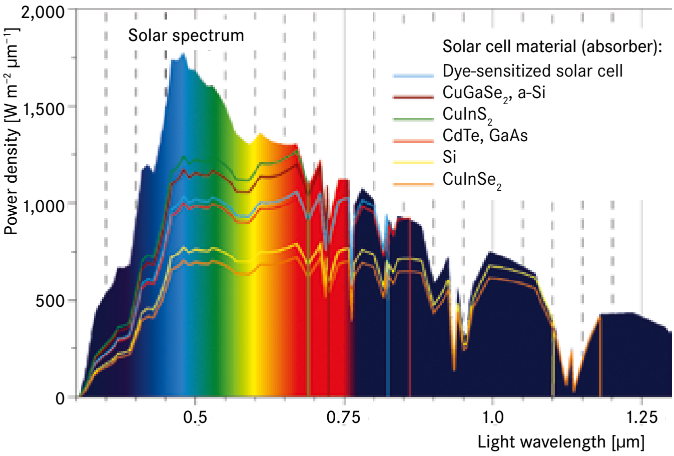
Concepts to increase efficiency

Researchers are also working on entirely new types of cells. They are combining nanostructures with organic materials, for example, or incorporating foreign atoms into absorber layers to improve solar cell efficiency. Another concept is that of so-called **tandems**, which consist of special stacks of light-activated materials.

To reduce cost of solar cells in the long-term, the costly indium in the absorber of a chalcopyrite cell can be replaced with zinc and tin, by which you get a kesterite structure.

Given that even the tiniest of changes in the layers of a solar cell can have major consequences, preparation and manufacture are particular challenges for the researchers.

Most solar cells cannot convert all frequencies (colours) of sunlight into electricity. The yield from light can be increased by combining absorber materials.



Solar cells must be producible in automated processes to be cost-effective.

COMBINE EXPERTISE, TRANSFER KNOWLEDGE

Not every product of research can be used in industry and not everything that industry and research need to know is taught. Solar energy experts from HZB and the Technische Universität (TU) Berlin have therefore founded the '**Competence Centre Thin-Film- and Nanotechnology for Photovoltaics Berlin**', PVcomB. Together with leading German thin-film photovoltaics companies, they bridge the gap between science and industry.

PVcomB unites the solar energy research at Helmholtz Zentrum Berlin with the **education of young scientists** at the Technische Universität and at the Hochschule für Technik und Wirtschaft Berlin. Furthermore, the competence centre brings publicly financed research together with top-level companies of the photovoltaics branch.

What is unique about PVcomB:

Knowledge is not merely passed on; it is refined by all partners together. For instance, new developments from pure research at HZB are made into 30 x 30-square-centimetre solar modules on two in-house production lines. Industrial partners can also use the facilities for their own experiments. The Berlin competence centre PVcomB tackles the issues of modern thin-film technology not only theoretically; it also tests them on industrial reference lines before implementing them.

www.pvcomb.de

PVcomB:

- Offers industrial partners ramp up support for new production lines
- Improves industrial processes
- Researches promising high-risk concepts
- Upscales basic research projects to the PVcomB standard size of 30 x 30 cm^2
- Operates its own reference lines as a benchmark for verifying processes
- Coordinates the curricula of universities with research and practical application
- Establishes professorships in response to real-world needs

HZB researchers use special technologies to develop thin-film solar cells.

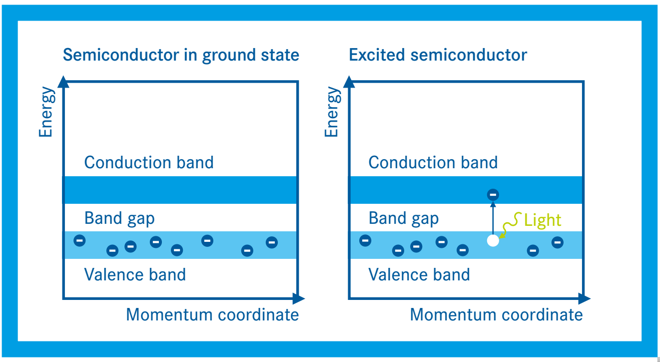
PRODUCTION UNDER CONTROL

Large scale, unique facilities and scores of different analytical methods give solar energy researchers at HZB a unique insight into matter. They not only learn whether something works; they also understand why. Solar cell manufacture is no longer a process of trial and error. Efficiency and industrial applicability can now go hand-in-hand.

Photoelectron spectroscopy, kelvin probe force microscopy, laser light scattering and analytical electron microscopy – for studying solar cells, the HZB researchers' list of analytical methods is long. Silicon research alone, for example, involves around 20 different methods to investigate solar cells and photovoltaic modules.

Directly comparing manufacturing processes

Aside from scanning electron microscopy, which allows to see the physical structure of a surface and the composition of the semiconductor films, these are methods that reveal the optical and electrochemical properties of materials. Many processes can already be analyzed while the solar cells are still in preparation. That means manufacturing processes are comparable.



The Band Model

The band model describes the electronic structure of a crystalline solid. Quantum theory states that excited electrons in the orbitals of an atom can only occupy discrete energy levels. The atoms in a solid are so densely packed that these energy levels 'blur' together into so-called bands. Semiconducting materials tend to form a valence band filled with electrons and a conduction band devoid of electrons. Between these is the band gap that is characteristic of every semiconductor. If electrons are to overcome the band gap for a current to flow in a solar cell, then the added light energy must be at least equal to the energy of the band gap. Accordingly, the band gap and band structure of a specific semiconductor determine which component of light in the solar spectrum can be used. HZB researchers use modern analytical methods to visualize these band structures and deduce the distribution of charge carriers.

Much of the work is done in cleanrooms.

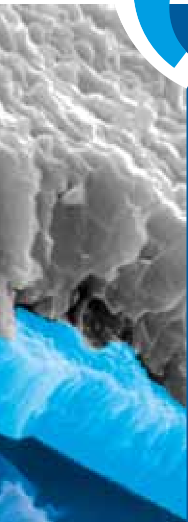
Critical matters like the boundaries between solar cell absorber layers and electrical contacts, or the structure of material-specific defects are studied by such methods as optically or electrically detected magnetic resonance and electron spin resonance spectroscopy.

Band structures become visible

Researchers can even make in situ observations – for example during the growth of a light-absorbing layer. They can characterize the optical, electrochemical and physical properties of a solar cell to great precision.

The researchers gain **unique insights** down to the level of chemical bonds using the synchrotron rays at BESSY II in Adlershof. This makes band structures visible, from which the distribution of charge carriers and thus the efficiency of a solar cell can be deduced. They can also use scanning tunnelling microscopy to observe how electrons behave when two different materials are combined.

HZB researchers need these precise analyses to understand how their materials behave when they alter manufacturing processes, modify materials or vary preparation methods.



Custom Boundaries

Modern thin-film solar cells consist of several material layers, each of different chemical and electrical properties. The conductivity of a solar module is influenced most of all by the boundaries between these layers. Accordingly, scientists in the junior research group ‚Boundary Design' are studying the structures of layer transitions in detail. Their goal is to establish analytical methods by which to characterize the boundaries of new solar cells and tune them precisely to the individual cell components.

Inserting a sample crucible into a system for thermo-gravimetric analysis (TGA). The thermal behaviour of catalysts or material mixtures is studied in order to understand thermal stability or to investigate reaction processes (e.g. catalyst synthesis) at increasing temperatures and in different gas atmospheres.

PRODUCING CHEMICAL FUELS

Fuels are chemical energy stores. Their energy can be converted into electrical, mechanical or thermal, and thus useful, energy by burning (oxidation). HZB researchers are investigating how the radiant energy of the sun can be captured and stored as a chemical fuel. **Their goal: Solar fuels.**

Take sunlight, water (electrolyte) and two photovoltaically active electrodes with integrated catalysts, connect them together, and light energy will already be converted into storable chemical energy. The principle is simple.

Water, in fact, can already be broken down into its constituents hydrogen and oxygen at a voltage of little over 1.23 volts.

Catalysts Wanted

If you want to obtain a large quantity of hydrogen – the energy store – in only a short time, then you need higher voltages. However, the resulting overvoltages reduce the efficiency of the system. Catalysts are therefore used to minimize the losses.

Various materials make suitable catalysts: **platinum,** for example, or **ruthenium dioxide.** While the materials currently used as catalysts are effective, they are often expensive, not sufficiently abundant or unstable in water.

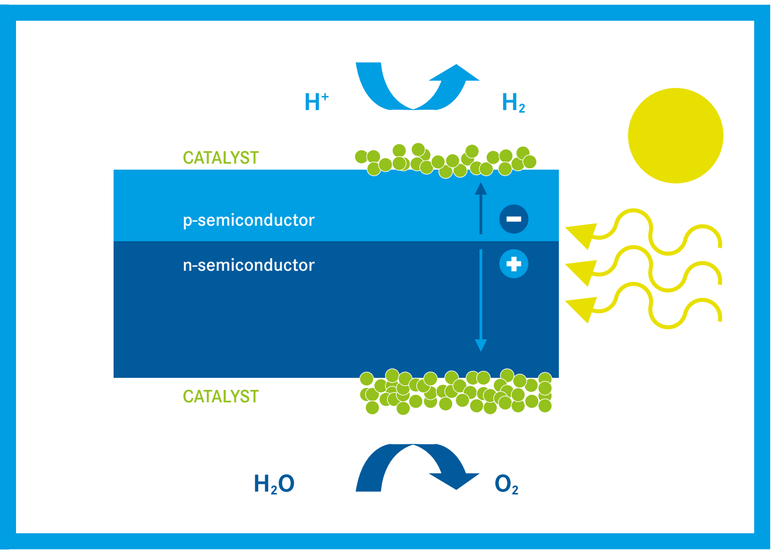
Researchers at HZB are therefore working on new catalysts. They are not only testing new materials. They are also increasing the catalyst surface areas by producing special **nanostructures.** Tiny catalyst particles are bound to the electrode surface using semiconducting substrates.

Solar-obtained hydrogen is an energy store of the future. Modern vehicles could be fitted with such a lightweight hydrogen tank, for example.

Artificially produced mono-crystals of $CuInS_2$ (top left), TaS_2 (bottom left) and PtS_2 (right)

Electrons released by sunlight from the semiconducting material migrate to the surface of the cathode, where they coax hydrogen out of the water. Now the researchers have to find out how to increase the voltage and electron flow between the electrodes in order to convert even more electricity into hydrogen.

In conducting their research, the scientists are grateful for **HZB's wealth of expertise in solar cell research.** The materials they are developing must possess more than just excellent electrochemical properties. They must also be highly photoelectrochemically efficient. That means the material must release as many electrons at as high a potential as possible as a result of light striking it. Ideally, the newly developed materials would be both **catalyst and semiconductor in one,** unifying catalytic properties with the ability to convert light energy into chemical energy.



Monolithic Systems for Producing Hydrogen

HZB researchers are working on producing hydrogen from water at the electrolyte-electrode boundary of a monolithic membrane. It combines a photovoltaic structure and suitable catalysts into a single water-splitting electrode. The conversion of light energy first into electrical and then directly into chemical energy is coupled with the catalytic processes at the electrolyte-electrode boundary. There, the incident light energy is chemically stored in hydrogen.

School students are engrossed in an experiment in the school laboratory (left) and a young researcher checks over an experimental setup.

ACTIVELY ENCOURAGING THE YOUNG GENERATION

HZB offers interested school students, school graduates, university students, PhD students and postgrad students many opportunities to learn and further their qualifications.

Sunny Prospects for Students

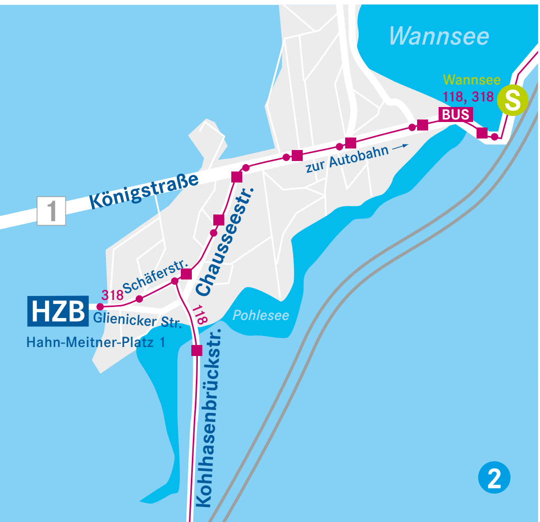
HZB collaborates closely with universities in Berlin and the Brandenburg region. Many of the senior researchers teach there and supervise students on their theses. Each year, a ten-day course on neutron scattering is held at HZB. An international school for photovoltaics and an eight-week, comprehensive **summer student program** are also offered. The programmes are a unique opportunity for students to familiarize themselves with laboratory work and with the large-scale scientific equipment at HZB.

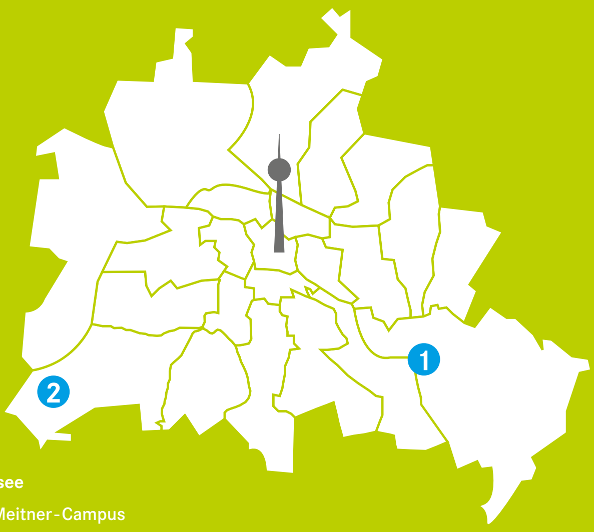
Hands-On Science

In the school lab, 'Blick in die Materie', school students can delve into the fascinating world of physics and incidentally get to know the work of a researcher. Young students who are interested can get a taste of the practical side of things in a practical course at HZB.

Successful Start to Professional Life

Young students also have the chance to be trained in a forward-looking profession such as administration, mechanical engineering, information technology or environmental and radiation protection.





Wannsee

Lise-Meitner-Campus

Hahn-Meitner-Platz 1
14109 Berlin
Tel +49 30 8062-0
Fax +49 30 8062-42181

Adlershof

Wilhelm-Conrad-Röntgen-Campus

Albert-Einstein-Str. 15
12489 Berlin
Tel +49 30 8062-0
Fax +49 30 8062-12990

Kekuléstraße 5
12489 Berlin
Tel +49 30 8062-0
Fax +49 30 8062-41333

PVcomB
Schwarzschildstraße 15
12489 Berlin
Tel +49 30 8062-0
Fax +49 30 8062-15677

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Helmholtz-Zentrum Berlin für
Materialien und Energie GmbH

Hahn-Meitner-Platz 1
14109 Berlin, Germany
Tel +49 30 8062-0
Fax +49 30 8062-42181

www.helmholtz-berlin.de