IMPACT

60 YEARS AMOLF


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IMPACT

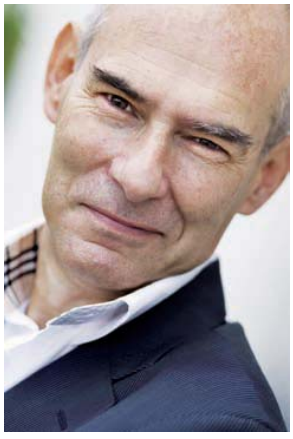
This book is dedicated to the researchers and support staff of AMOLF between 1949 and 2010.

The texts in this publication have been written by the research group leaders who have shaped AMOLF's research during the last sixty years. They have made AMOLF what it is today: a leading international research institute. They were asked to describe the highlights of their research and this book is the result. I would like to thank them sincerely for their contributions.

This book is not an exhaustive overview of all the research that has been carried out at AMOLF since 1949. It does, however, convey what has been AMOLF's most significant characteristic for sixty years: a continuous flow of new ideas, each leading to new avenues in the research programme and each based on the most important criterion: a passion for science.

Albert Polman • Director of FOM Institute AMOLF

60 years of FOM Institute AMOLF



AMOLF is one of the FOM foundation's national research institutes. It operates under the umbrella of the Netherlands Organisation for Scientific Research (NWO) and has been a beacon in the landscape of Dutch physics for sixty years. It is an exponent of dynamic physics research, with a broad spectrum of research lines that evolve rapidly and are always innovative. It is restless, brilliant and continually on the move, but the spirit, infinite flow of ideas, ambition and uncompromising dedication to research are constant factors at the institute. As is the proud awareness of being one of the top research laboratories in the world. The FOM institutes are absolutely essential for FOM and must achieve international excellence. That applies to the staff, the host of research topics, the equipment, the location and, it goes without saying, the building. AMOLF is ready to face the future with confidence.

Niek Lopes Cardozo • Chairman of the Executive Board of FOM

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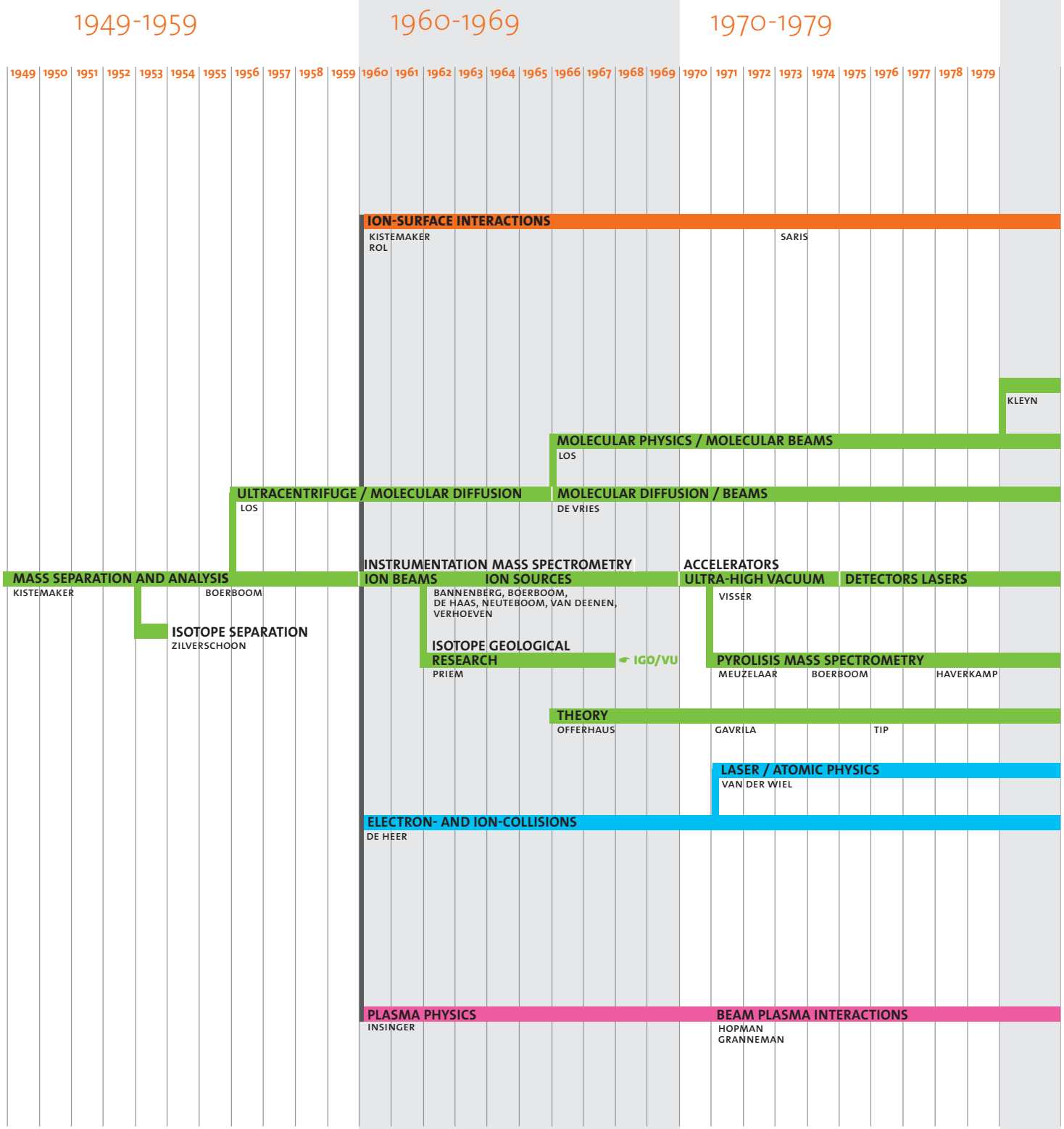
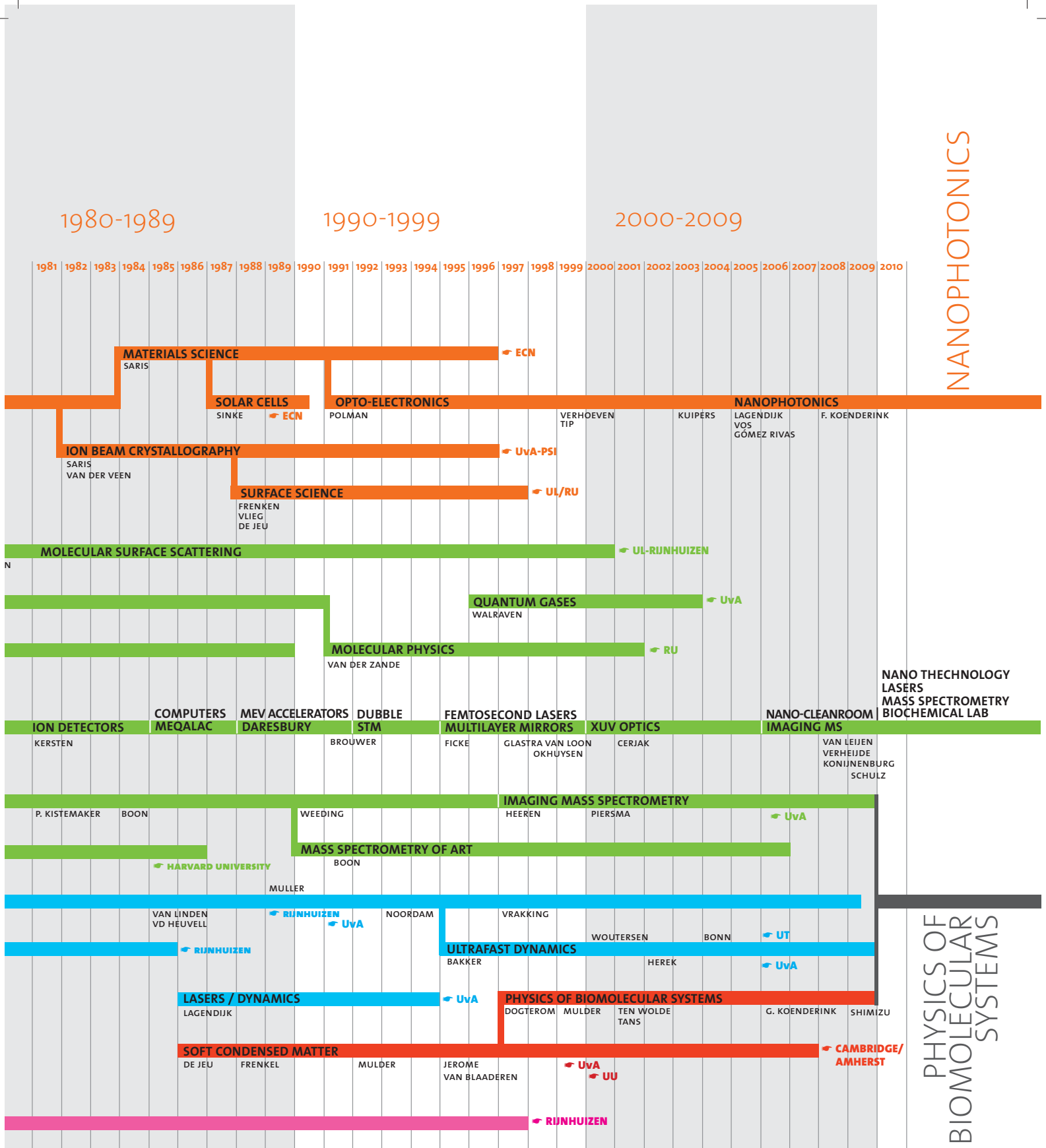
AMOLF'S RESEARCH TREE



NAMES REFER TO THE GROUP LEADERS, IN THE YEAR IN WHICH THEY STARTED AS A GROUP LEADER ☛ SHOWS THAT (A PART OF) THE ACTIVITY MOVES ELSEWHERE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MATERIALS SCIENCE
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SOLAR CELLS
SINKE
ECN
OPTO-ELECTRONICS
POLMAN
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TIP
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NANOPHOTONICS
LAGENDIJK
VOS
GÓMEZ RIVAS
F. KOENDERINK
ION BEAM CRYSTALLOGRAPHY
SARIS
VAN DER VEEN
UvA-PSI
SURFACE SCIENCE
FRENKEN
VLIEG
DE JEU
UL/RU
MOLECULAR SURFACE SCATTERING
UL-RIJNHUIZEN
QUANTUM GASES
WALRAVEN
UvA
MOLECULAR PHYSICS
VAN DER ZANDE
RU
NANO THECHNOLOGY
LASERS
MASS SPECTROMETRY
BIOCHEMICAL LAB
ION DETECTORS
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COMPUTERS
MEQALAC
MEV ACCELERATORS
DARESBURY
DUBBLE
STM
BROUWER
FEMTOSECOND LASERS
MULTILAYER MIRRORS
FICKE
GLASTRA VAN LOON
OKHUYSEN
XUV OPTICS
CERJAK
NANO-CLEANROOM
IMAGING MS
VAN LEIJEN
VERHEIJDE
KONIJNENBURG
SCHULZ
IMAGING MASS SPECTROMETRY
P. KISTEMAKER
BOON
WEEDING
HEEREN
PIERSMA
UvA
MASS SPECTROMETRY OF ART
HARVARD UNIVERSITY
BOON
MULLER
VAN LINDEN
VD HEUVELL
RIJNHUIZEN
UvA
NOORDAM
VRAKKING
WOUTERSEN
BONN
UT
RIJNHUIZEN
ULTRAFAST DYNAMICS
BAKKER
HEREK
UvA
LASERS / DYNAMICS
LAGENDIJK
UvA
PHYSICS OF BIOMOLECULAR SYSTEMS
DOGTEROM
MULDER
TEN WOLDE
TANS
G. KOENDERINK
SHIMIZU
SOFT CONDENSED MATTER
DE JEU
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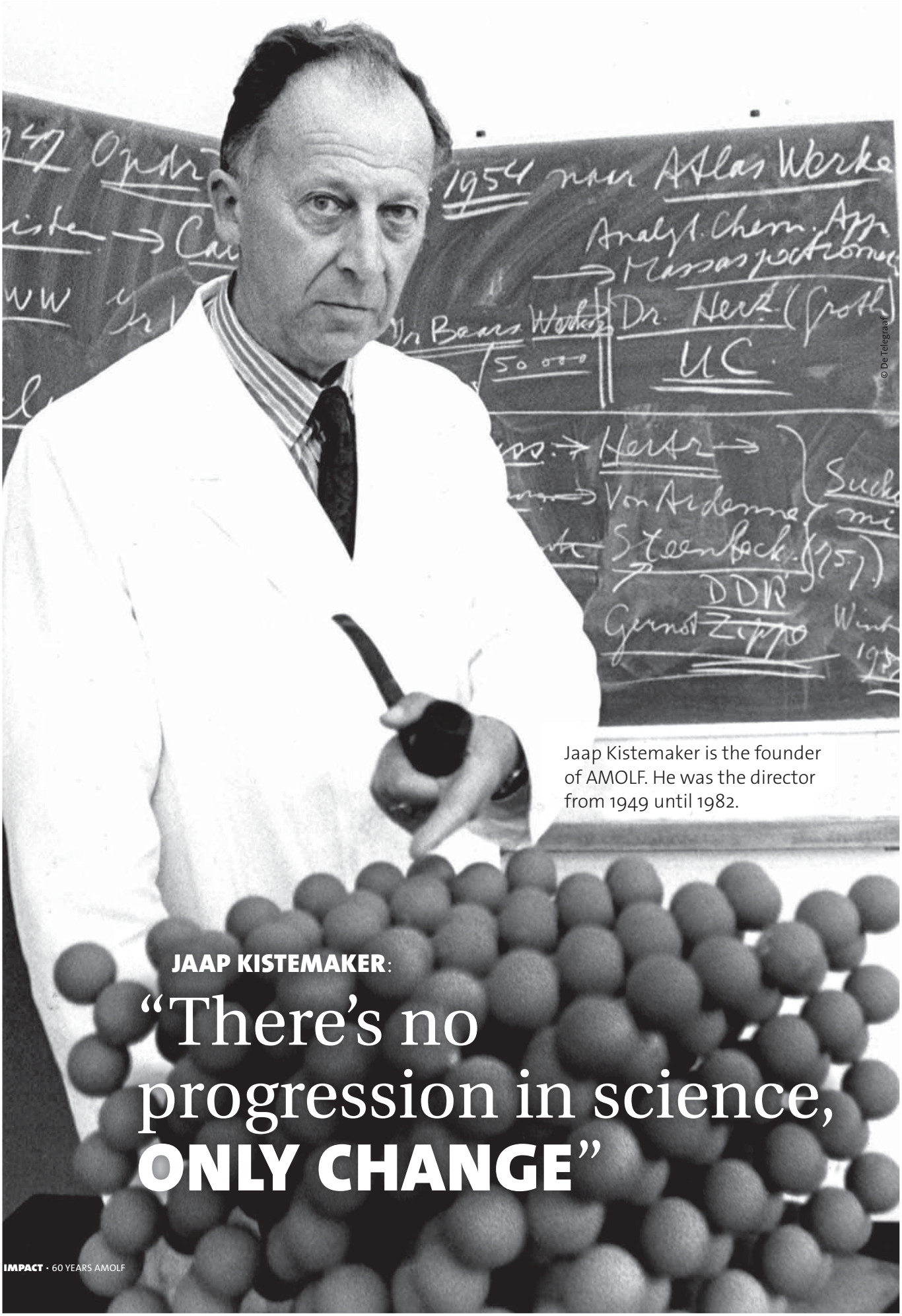

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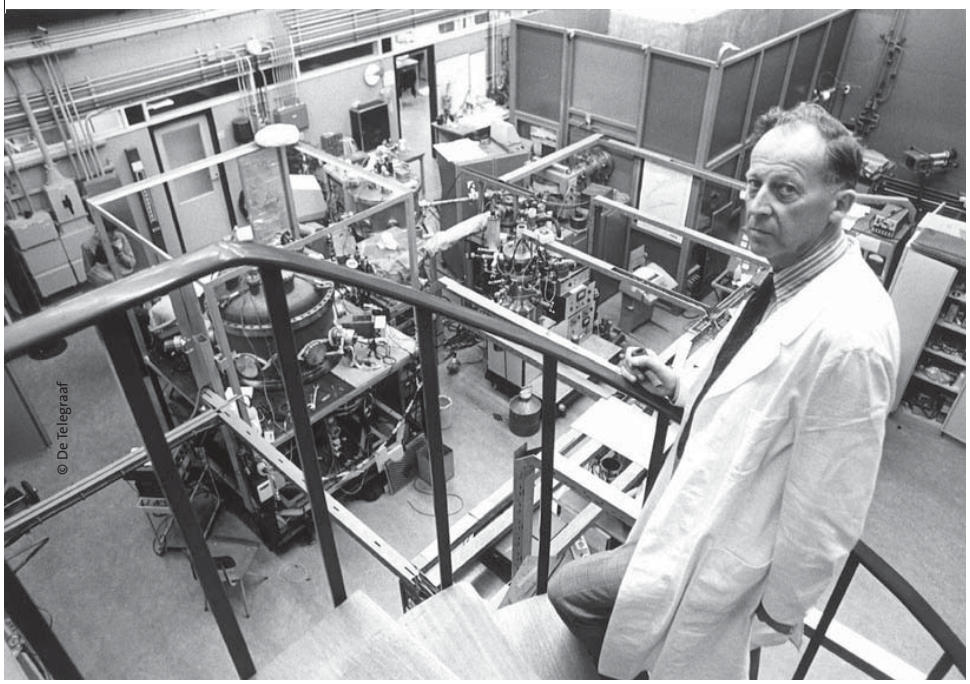
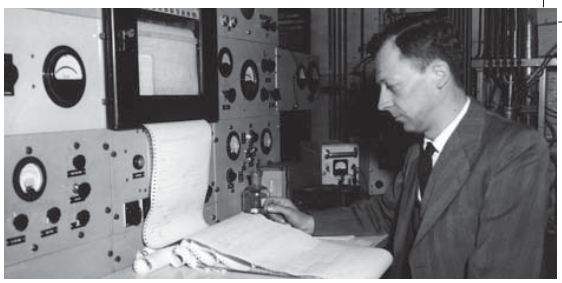
Jaap Kistemaker is the founder of AMOLF. He was the director from 1949 until 1982.

JAAP KISTEMAKER:

"There's no progression in science, **ONLY CHANGE**"



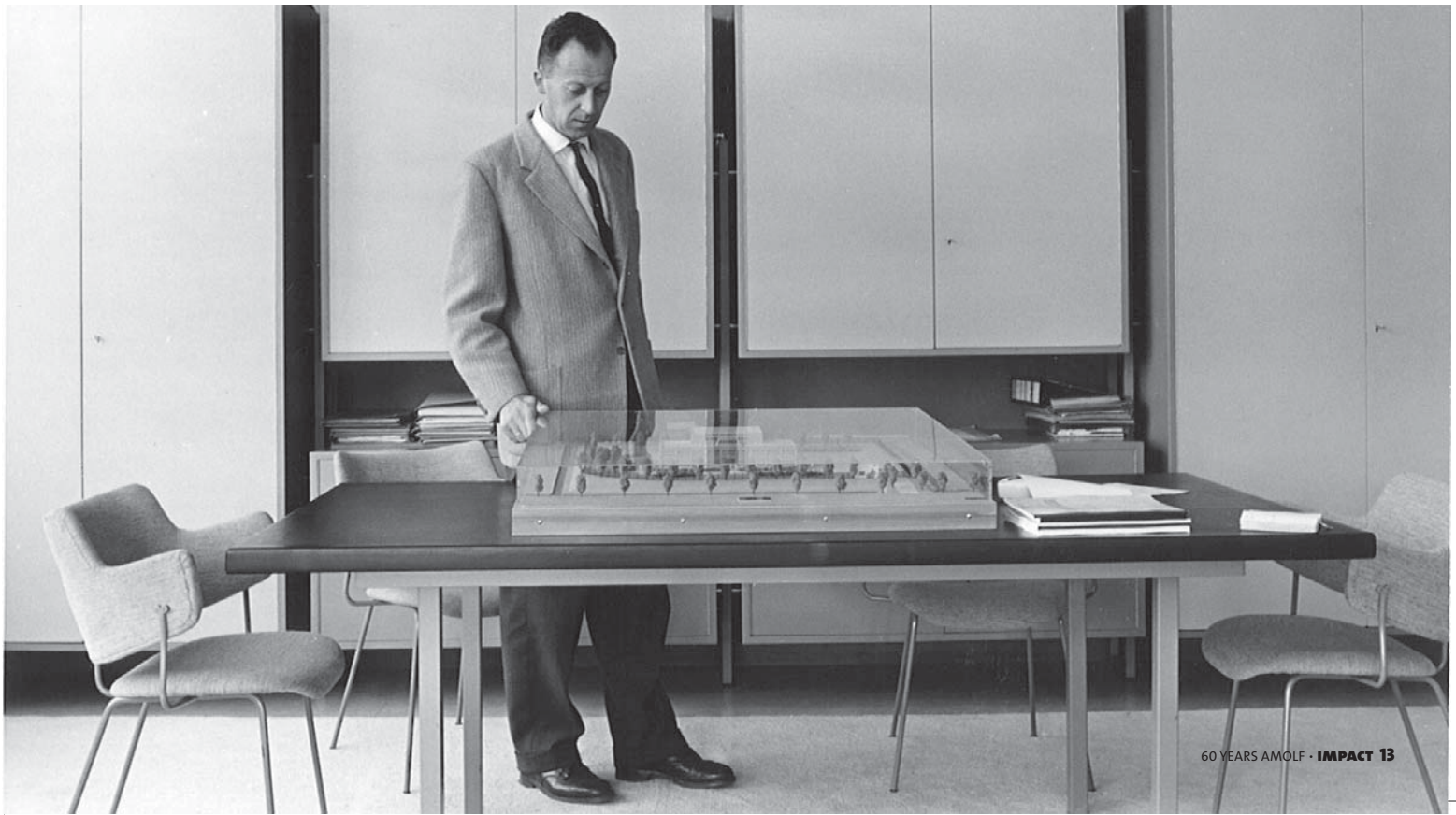


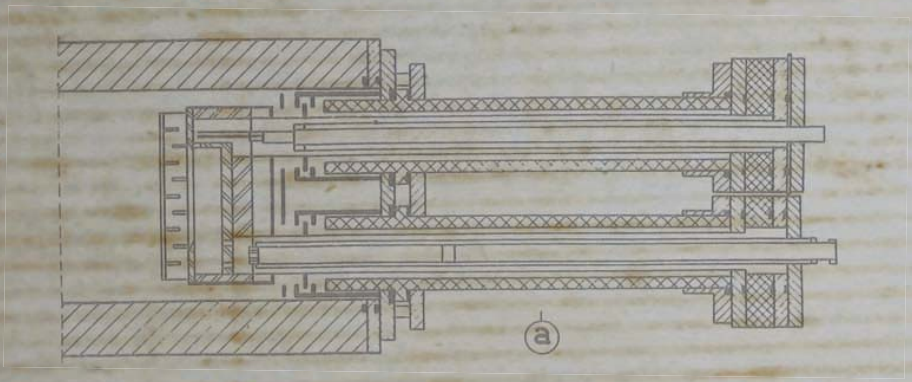
HOW IT BEGAN

"One day in October 1945, my doctoral thesis supervisor Prof. Kramers came into my room with a small yellow book that had just been delivered by special courier from Washington. It was the Smyth Report on the Manhattan Project and I had 24 hours to read it. There was no such thing as photocopying in those days. A few months later a government commission decided that I had to go to Niels Bohr in Copenhagen to familiarize myself with electromagnetic separation. I knew little about nuclear physics and even less about industrial technology. I was 28 years of age, married and our daughter was two months old".

BRAINSTORMING

In 1960, the Dutch weekly journal 'Katholieke Illustratie' described Kistemaker as follows: "In the beginning, the cool West Friesian farmer's son from Kolhorn did not at all meet the caricatural notion that most laymen have of a 'scarily clever nuclear physicist'. (...) He was a calm, quiet intellectual with attentive grey eyes which would wrinkle up with laughter if he was surprised by a remark". We asked Kistemaker whether he ever reached the point at which a particular study ground to a halt. "Oh yes, but we have a solution for that. We 'brainstorm'. We put our heads together and everyone has to say what comes up in them, no matter how ridiculous it sounds. It is exhausting, but together you sometimes arrive at amazingly funny things."•

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THE 1950s

These were the post-war reconstruction years. The Netherlands had lost its leading position in physics because of the war. We had to catch up in this new area of nuclear physics and the Dutch government sent Jaap Kistemaker to Niels Bohr in Copenhagen to familiarize himself with uranium isotope separation. The Foundation for Fundamental Research on Matter (FOM) was founded and, in 1949, it decided to start an institute for mass spectrography.

1949···1959

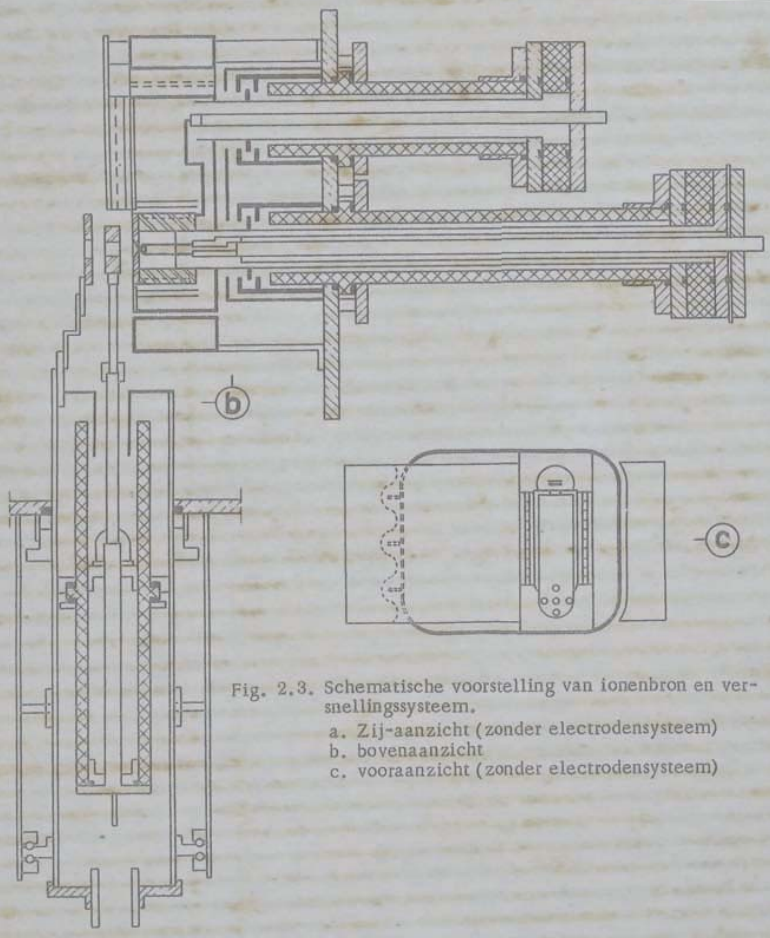


Fig. 2.3. Schematische voorstelling van ionenbron en versnellingssysteem.
a. Zij-aanzicht (zonder electrodensysteem)
b. bovenaanzicht
c. vooraanzicht (zonder electrodensysteem)

The specially designed shape of the wings of the ion source enables the generation of a high voltage. The code word was 'Mae West', after an American film star with a famous profile.

HIGHLIGHTS 1949-1959

The FOM laboratory for Mass Spectrography was opened on 15 September 1949. The task of the institute was to find out how to separate uranium isotopes. The research concentrated on the construction of a large electromagnetic isotope separator. The first sample (10 mg) of enriched ^{235}U was made in 1953. In 1955, as a result of the Dutch developments, the American Congress decided to 'declassify' electromagnetic uranium separation technology. Enriched uranium was being produced at various places in America and England, and on a larger scale than at FOM. Uranium and other radioisotopes became available for research and for medical applications whereupon Kistemaker and Los started a new project: the enrichment of uranium from UF_6 using gas centrifuges. This was realized together with the newly established Reactor Centrum Nederland (RCN). In 1959, the FOM institute moved to a new location on the Kruislaan and was given the new name FOM Laboratory for Mass Separation.

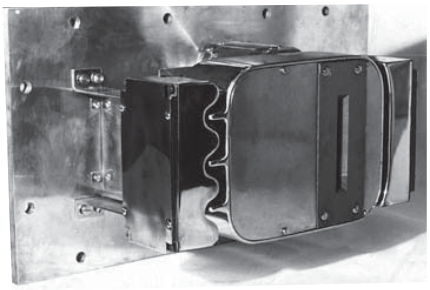
1949

The seperator's first test measurement

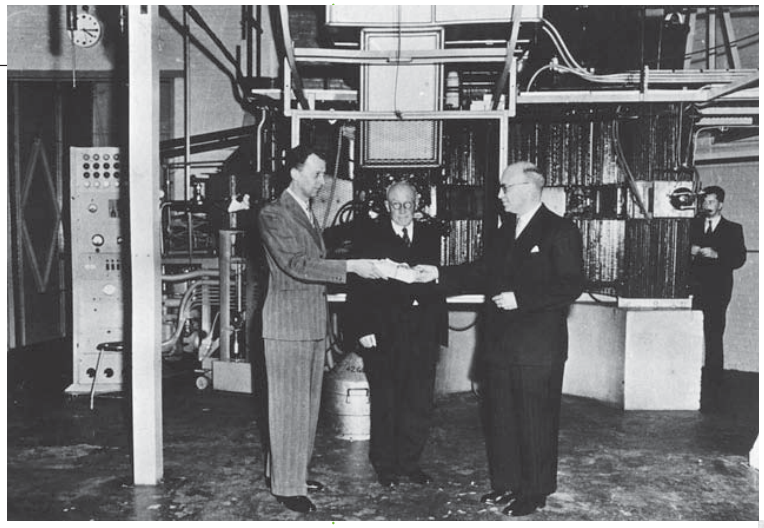
1953

Uranium isotope separation

Jaap Kistemaker handing over the first enriched uranium to the chairman of the FOM foundation. The isotope separator, a 40-ton electromagnet with pole shoes of a diameter of 2 metre and a field strength of 3000 Gauss, is visible in the background. Uranium ions (25 kV, 10 mA) were generated from UCl_4 gas in a vacuum chamber which was placed in front of the poles of the magnet. The specially designed shape of the wings of the ion source enables the use of high electrical voltages without the discharge of electricity. The code word was 'Mae West', after an American film star with a famous profile.



1954



F.l.t.r.: J. Kistemaker, J. Clay, J.M.W. Milatz

Visit by Lawrence

Visit to the FOM Institute by Ernest Lawrence, Director of the Radiation Lab of Berkeley University in California, USA, on the occasion of the first uranium isotope separation experiment.

First doctorate

The first student to obtain a doctorate with Jaap Kistemaker was F.J. de Heer, at the University of Amsterdam, in the year 1954.

F.l.t.r.: J. Kistemaker, J. Clay, C.J. Bakker and E.O. Lawrence

AMOLF'S FIRST SCIENTIFIC ARTICLE

'Investigations on a magnetic ion source I'

J. Kistemaker, H.L. Douwes Dekker, Physica (1949)
An ion source of the magnetic type has been developed, using oscillating electrons, and with the filament quite near the ion extraction hole. Space charge limited ion currents have been obtained ranging from 5 to 10 mA using extraction potentials of 6 to 15 kV. Hydrogen, helium and nitrogen gas have been used, showing an apparent mass effect. No influence of the pressure on the extracted ion current was experienced in the pressure region from 10^{-5} - 10^{-3} mm Hg.
An experimental comparison between our source and the usual type has been carried out and the ion outputs show only small differences.

1955

'Declassification' of isotope separation in the USA

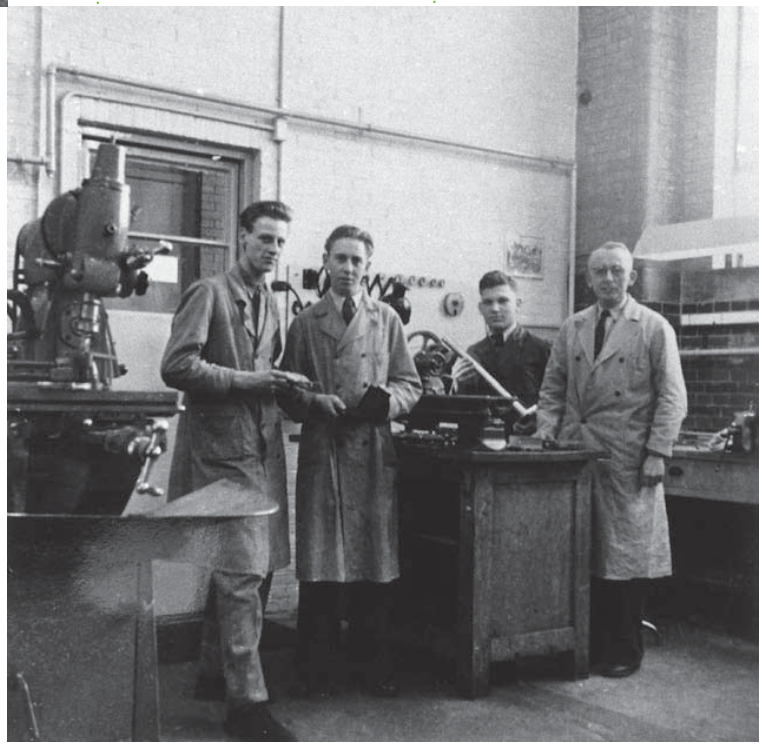
The first international conference on isotope separation was held in Amsterdam whereupon the Americans and Britons decided to end the secrecy regarding atomic research and make radioactive isotopes available for science and medical research.

1958

Isotope enrichment for ^{14}C age determination

A. Haring, A.E. de Vries and H. de Vries, Science 128, 472 (1958).

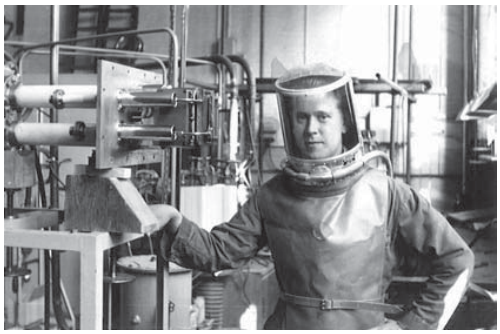
The accuracy of the age determination method using ^{14}C was considerably improved by isotope enrichment in a 5-metre-long thermal diffusion column. This made it possible to go back 70,000 years in time. The technology was calibrated by comparing the enrichment of $^{14}C^{16}O$ and $^{12}C^{18}O$.

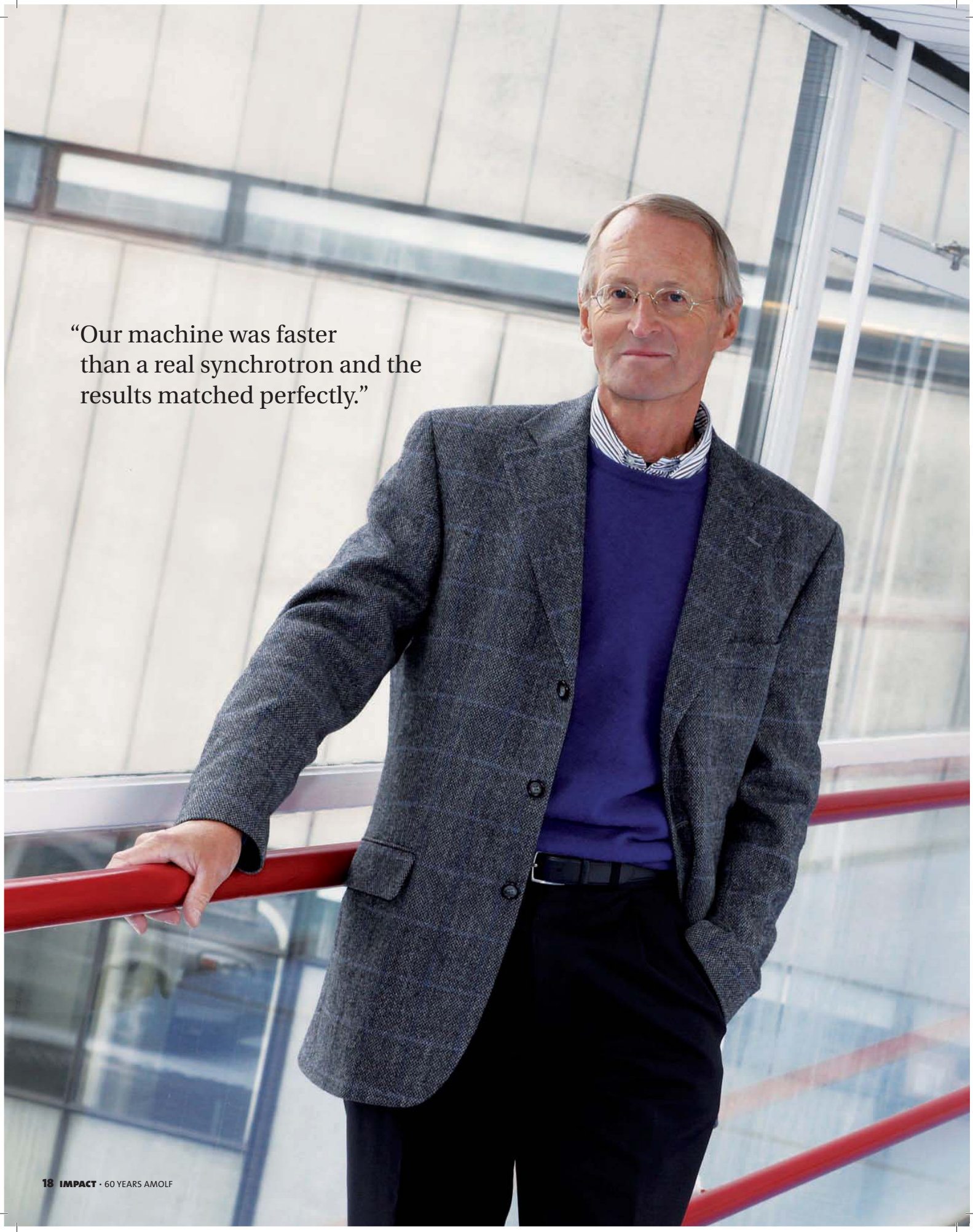


1959

Spectroscopy of atomic collisions

This was the beginning of decades of research on excitation, ionization and electron capture processes in electron and ion-atom collisions.





"Our machine was faster than a real synchrotron and the results matched perfectly."

MARNIX VAN DER WIEL

"I asked myself: **HOW DO I MAKE A TABLE-TOP SYNCHROTRON?**"

Marnix van der Wiel carried out his graduation research (which he started in 1963) at AMOLF and subsequently also his doctoral research. After a short postdoctoral research period in Canada, he returned as a group leader in 1972 and held this post until 1986. From 1977 he was also a deputy director. From 1987 to 1998 he was the director of the FOM Institute for Plasma Physics Rijnhuizen. Van der Wiel subsequently worked at Eindhoven University of Technology until his retirement.

"Ionization can be realized with photons and electrons. Devices known as synchrotrons (large user facilities operated by many researchers) were developed in the 1960s for measurements on photo-ionization. When I was carrying out my graduation research at AMOLF, I worked on the total collision cross section of ionization by electrons. The theory now showed an intriguing, but well-hidden link between ionization by rapid electrons and that by photons. I then went more deeply into the theory and also discovered a much more direct connection which became clear if you looked solely at the energy loss of electrons that continued forwards after a collision.

This gave me the idea of making a sort of model synchrotron myself, which, by taking measurements on electrons, would enable us to find out more about ionization by photons. The then director, Kistemaker, gave me the chance to build one. That was pretty unique, because it really was a very ambitious plan for a doctoral student. I had only made an outline on a single sheet of A4 paper and he liked the look of it. I was given unlimited access to the technicians and the drawing room. It went very fast. The electrotechnicians were invaluable in developing the so-called coincidence switching. That is, in fact, the essence of the set-up; the part that connects the measurements of two particle detectors.

The point at which we saw the first coincidences was incredible. We knew it ought to work if signals came from both detectors – however, seeing is believing. This was proof that our device worked – and it worked well too. Our results corresponded brilliantly with the first results from the real synchrotrons, but our device was much faster and easier to operate. Furthermore, it was the first fully-automatic set-up at AMOLF. An entire measurement easily took 24 to 36 hours. I did not have to sit there and wait beside it, though, I only had to come back to top up the liquid air. This 'poor man's synchrotron' enabled us to do many years of wonderful research and the principle behind it was also used in transmission electron microscopy (TEM) a while later.

You might wonder whether those big synchrotrons still had any value, if the measurements could just as well be carried out with a table-top synchrotron like ours. A real synchrotron can, however, carry out many more types of measurements than just quasi photo-ionization, such as diffraction. Secondly, it is also a question of convenience, I think. Many physicists do not want the bother of building their own device; they prefer to have everything ready and waiting so that they can carry out their measurements straight away.
I personally prefer the kick of developing a method, showing that it works, doing great physics with it for a while and then passing it on." •

Jaap Kistemaker 1949-1982
Joop Los 1982-1986
Frans Saris 1986-1996
Jook Walraven 1996-2002
Bart Noordam 2002-2005
Albert Polman 2006-now

AMOLF'S DIRECTORS

AMOLF blossomed and grew under the inspired leadership of six directors. Who were they and what did they do for the institute?

Frans Saris gives his impressions of his predecessors, Jaap Kistemaker and Joop Los:

"**Jaap Kistemaker** did physics that was worth doing and he was in the middle of society. The latter provided him with research topics and staff. Conversely, AMOLF was a major supplier to industry. The short-term policy that still characterized AMOLF, was completely unique in the 1970s. Jaap Kistemaker once said, "It is a privilege to work here and your right has run out." This was absolutely impossible in a time of permanent employment, and yet it worked. Drinking coffee together was, in his opinion, the secret of a good lab. Physicists who drink coffee together do not talk about women or cars, but about physics. During this ritual, ideas were generated, pats on the back were given and disappointments were dealt with."

"**Joop Los** was appointed director in 1982. He was a totally different administrator than his predecessor. People respected him and he got his way by means of friendly negotiations. Although he was only at the helm for a short period, he was partly responsible for making AMOLF into a dynamic organization where three quarters of the employees are temporary. Moreover, he was without doubt the best physicist AMOLF has ever had. He was the first to become a member of the Royal Netherlands Academy of Arts and Sciences (KNAW) and the first to receive the Dutch Physica Prize. Whereas his predecessor had set up an excellent technical lab, we are indebted to Joop Los for the fact that we rank with the scientific top."

Frans Saris was appointed director in 1986: "I was at AMOLF when both Jaap Kistemaker and Joop Los were directors and I learned a lot from both of them. I continued the typical AMOLF policy of dynamism and turnover without altering it and even suffered myself in the process. When I took office, the FOM foundation decided that an AMOLF director could only hold the position for five years and that he or she could only stay on for a maximum of two terms. I regretted this. Indeed, without this rule, I would have stayed on as director until I retired. I was in my element there. In retrospect, it was good for AMOLF. If I had remained, Albert Polman would not have been able to achieve what he already has."

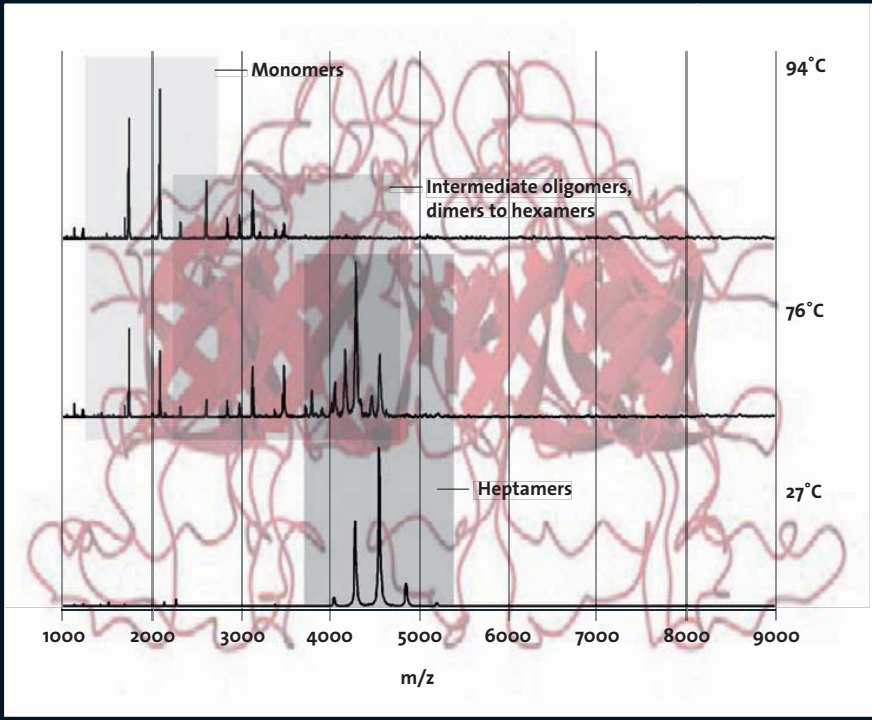
In 1996 **Jook Walraven** became the director: "On my appointment, it was explicitly the idea that AMOLF would raise its profile in the physics of living systems. It was up to me to set out the new course. I also realized that we could only stay at the top for the coming fifty years if we had a new building. People were very attached to the original accommodation, but it had been built for an entirely different sort of research. Soon all the personnel were taking a positive stance about a new building. This constructive atmosphere is characteristic. Everyone at the institute focuses on getting the best out of themselves and AMOLF as a whole."

Walraven was succeeded by **Bart Noordam** in 2002: "AMOLF's power comes from the collective. As director you have to do two things: see that you have capable people and subsequently make sure that the whole equals more than the sum of its parts. There are all sorts of mechanisms you can use to achieve this, and all the directors have added their own elements. I myself introduced the weekly director's announcements during the joint coffee break. I put someone in the limelight or paid particular attention to a member of staff who was leaving. AMOLF is continually rejuvenating itself and the director has a role in this too. I was able to recruit five new group leaders within a few years. That meant that we had all the big names in Nanophotonics in house and we could really get AMOLF onto the map in this new field."

Albert Polman has been the director of AMOLF since 2006: "When I started as director, AMOLF was going through a transition period. The institute had focused strongly on two main research directions and it was now our task to reach the top in these fields. At the same time, it became very important to tighten our links with the outside world, the universities and industry. I have made every effort to achieve this. A great moment was when I asked all the group leaders whether they could contribute to solving the energy problem: a large number of very interesting ideas were put forward and, if it is up to me, energy research will become one of our new themes. But the best thing that has taken place in the last year is, of course, the completion of the new building. AMOLF's future looks bright for the next sixty years!" •

EXTREEM

THE HEAVIEST ION
70 kDa WEIGHED USING MASS SPECTROMETRY



R.B.J Geels et al. Rap. Comm. Mass. Spec. 22, 3633 (2008).

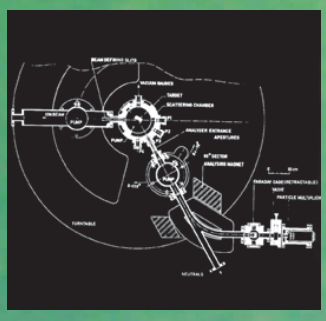
The heaviest ion to be captured in a Penning trap of the FTICR mass spectrometer is a multiple charged ($[M+19h]^{19+}$) 70-kDa heptamer of GroES, a part of the Chaperone complex GroES-GroEL.

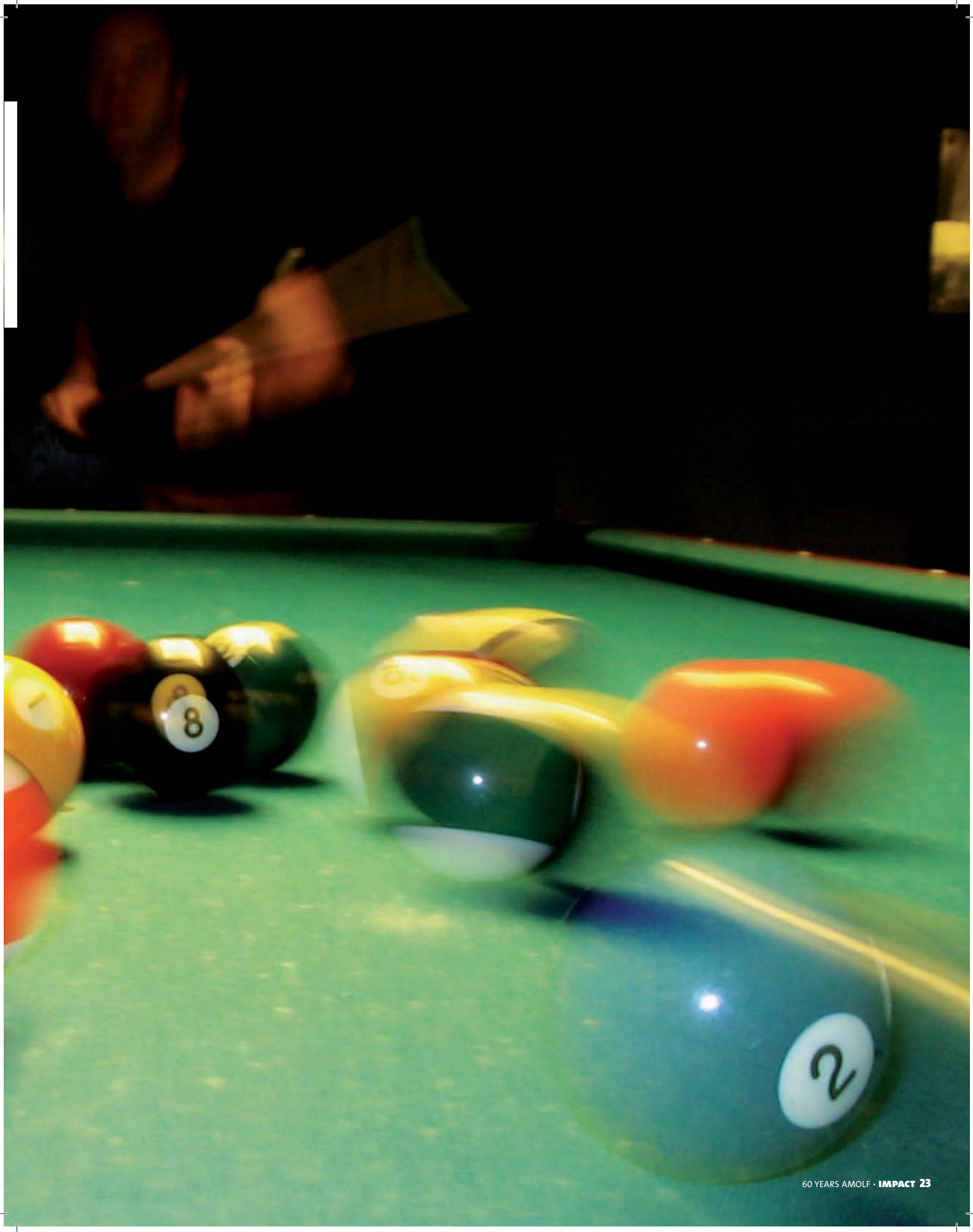
THE 1960s

During this period, AMOLF focused on fundamental research in atomic and molecular physics. The study of the 'billiard game' of interaction between electrons, atoms, molecules and surfaces greatly increased our understanding. New set-ups were built for experiments on molecular collisions. The new facilities needed to this end were developed in house with the extensive technical staff. It took considerable effort on AMOLF's part to acquire a position in the research community in the Netherlands and abroad.

1960…1969

Datz and Snoek's instrument, in which an ion beam is scattered onto a copper surface (doctoral thesis of C. Snoek, 1966). The secondary ions were analysed with a magnetic sector mass spectrometer.

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HIGHLIGHTS 1960-1969

The principle of the ultracentrifuge was developed in the period 1956-1962. The research focused on the mechanics of rapidly-rotating drums in which UF_6 gas is separated. The first objective was achieved in 1962, after which the research phase was complete and the technology was transferred to various industrial parties, the initial one being Werkspoor. Urenco was established later on the basis of this work; this organization has since expanded into a large international company. Isotope geological research became an independent NWO institute and was based at the Free University Amsterdam. Subsequently the institute had to reinvent itself. It focused on fundamental research into the original underlying physical processes of isotope separation, at the same time focussing on new applications. Various new experimental set-ups were built to study the interaction of electrons, atoms, molecules and surfaces. Plasma physical research into high-temperature plasmas using beams was started, the ultimate objective being to achieve nuclear fusion for the generation of energy. In 1966, the institute was given a new name: the FOM Institute for Atomic and Molecular Physics (AMOLF).

1960

New building

The new building on Kruislaan was officially opened by Minister Cals on 10 October 1960. The institute was renamed the FOM Laboratory for Mass Separation. At that stage the institute had 69 employees. Jaap Kistemaker was the director, Joop Los deputy director.

1962

AMOLF's ultra-centrifuge project results in Urenco

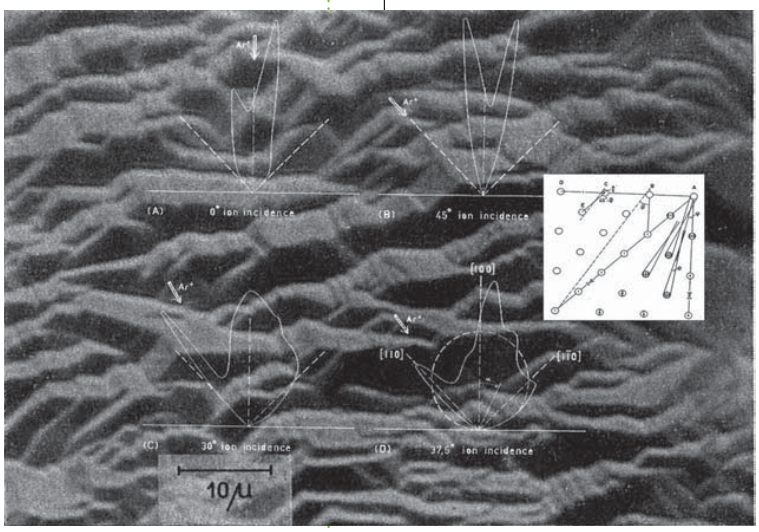
In 1962, the ultracentrifuge research at AMOLF was stopped and transferred to Werkspoor. Later it was transferred to Stork, after which, in 1969, Urenco was established. Since 1982, Urenco (Almelo) has been one of the largest producers of enriched uranium in the world. The production process is based on the ultracentrifuge technology that originated at AMOLF. Urenco's annual turnover in 2009 was more than 1 billion euros.

1963

Discovery of 'channelling' of ions in crystals

J.M. Fluit, P.K. Rol

When monocrystalline copper is bombarded with argon ions, copper atoms sputter from the surface. It became apparent that the quantity of sputtered copper atoms depends on the crystal orientation. If the ion beam is oriented along a main direction of the copper crystal, the ions channel into the crystal without sputtering copper atoms out of the surface.



Prof. Kistemaker's big adventure

Excerpt from Elseviers Weekblad (a Dutch weekly), 12 April 1969
In 1955, a young scientific researcher walked into the Werkspoor Board Office. His name was Dr J. Kistemaker and he had been carrying out research in the field of uranium enrichment for years. He had just attended a scientific congress in Hamburg where he had heard German scientists speak about the use of ultracentrifuge to enrich uranium. And he was quite determined to find a financer and specialize in the field of ultracentrifuge.

1965

Instrumentation for plasma physics

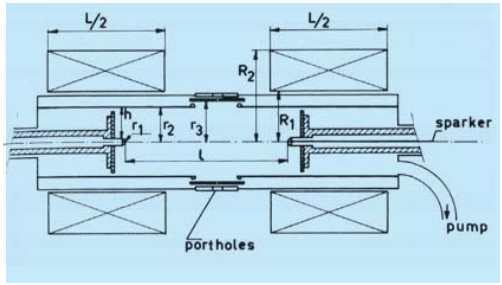
Jan Bannenberg designed and built an instrument with which the heating of plasmas could be measured. He succeeded Schutten as technical director and stood, together with Boerboom, at the cradle of many innovations: the 200-keV accelerator, Torus, Tuba, AMI, the channel plate detector, pyrolysis, MEQALAC and MeV accelerators.

1968

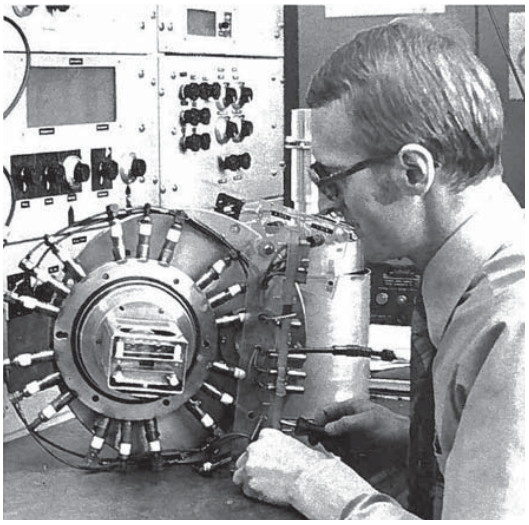
The 'poor man's synchrotron'

M.J. van der Wiel and G. Wiebes, Physica 53, 225 (1971).

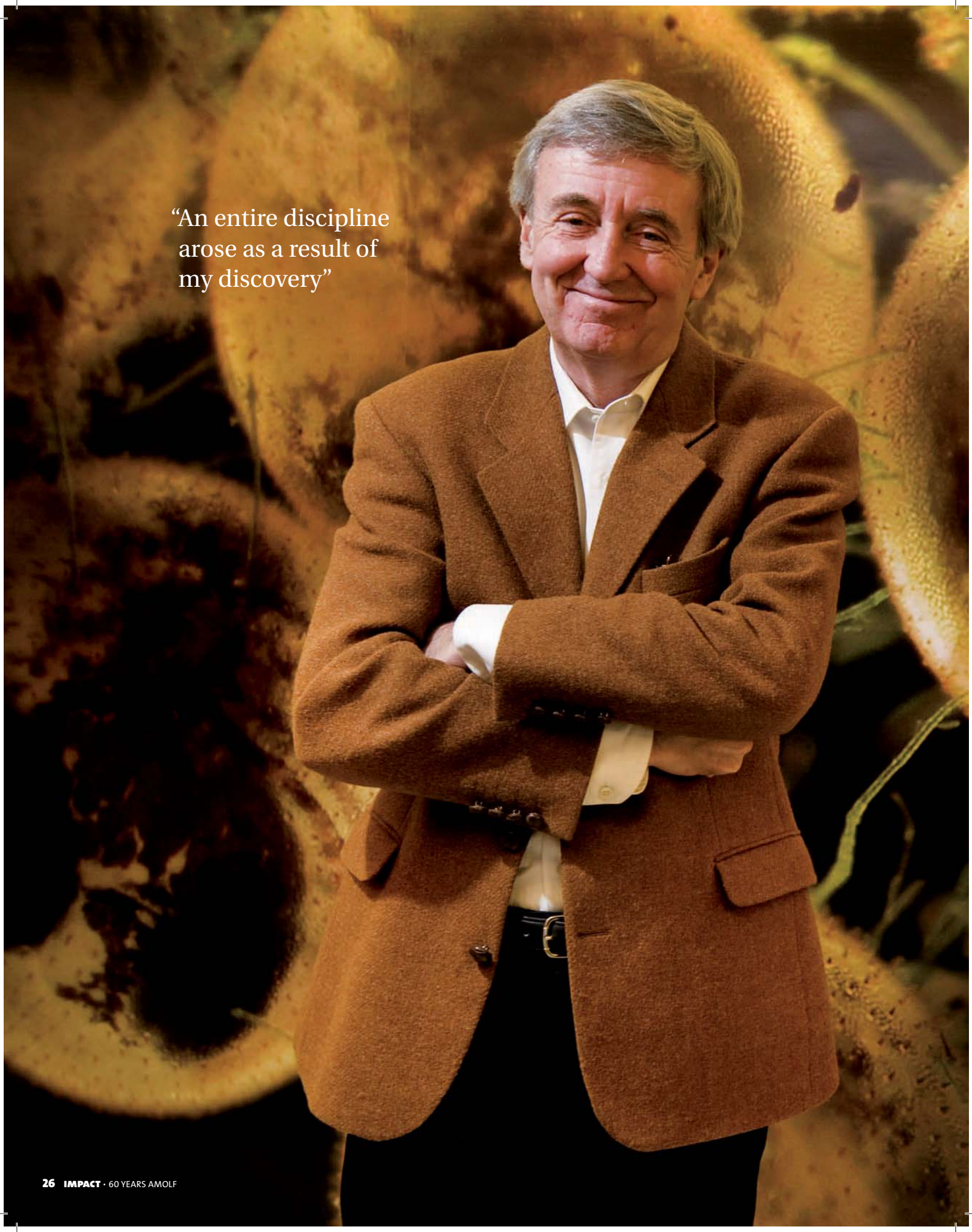
AMOLF enjoyed two 'firsts' around 1970: the first use of 'single-particle' detectors and the linkage of these detectors to a coincidence circuit. Consequently, forward scattered electrons and ions formed during collisions could now be measured. This yielded oscillator strengths for multiple ionization, for instance, which were quantitatively comparable with the results achieved with synchrotron radiation. And it took a fraction of the measuring period.



Electrode system with magnetizing coil for plasma physics



Marnix van der Wiel sitting at the operating panel of the 'poor man's synchrotron' with a part of it on the table


“An entire discipline
arose as a result of
my discovery”

FRANS SARIS

“I asked myself: WHERE DOES THAT RÖNTGEN RADIATION COME FROM?”

Frans Saris came to AMOLF to carry out his graduation research in 1964 and his doctoral research from 1967 to 1971. He was a deputy group leader for a year before he left for Canada. In 1973, the then director, Kistemaker, asked him to come back. Saris was a group leader until 1996, and was also the director of the institute from 1986 to 1996.

“When I was doing my doctoral research, Jaap Kistemaker visited the USA for a working trip and saw that Röntgen radiation was created if you bombarded atoms with protons. He sent me a telegram asking me to look at whether this would work with argon ions too. I tried it out and, when he returned, was able to show him that argon also produced the radiation in question. Later we repeated the experiments with other ions and made a startling discovery. It appeared that, in addition to the characteristic radiation for the element under examination, all the spectra also contained a sort of continuum of undefined radiation.

I had an idea about where it might come from. I suspected that the radiation that the ions emit at each moment of the collision was characteristic of the short-lived molecular state that the colliding ions formed at that moment. On further analysis, it appeared that, at a certain time, two colliding argon ions did indeed emit radiation that matched krypton, an element that is twice as heavy as argon. They formed a krypton atom for a very brief moment, as it were.

That discovery attracted a great deal of attention from the entire scientific world. Everyone thought it was fantastic. I received two important Röntgen prizes within a short period of time and all sorts of offers to become a professor. There was particular interest from the world of nuclear physics, because the big question was what would happen if you had two uranium atoms collide with one another. Attempts to make super heavy elements were in full swing at the time.

I was naturally very honoured by all the interest and offers. An entire discipline arose as a result of my discovery alone but, to be honest, I did not personally think that that area was worth much more exploration. I refused the offers because I preferred to work as a group leader at AMOLF. I studied Röntgen radiation there for a number of years and then I switched to research on silicon.

Despite the fact that my discoveries were fundamentally interesting, my feeling that the new discipline would fizzle out like a damp squib was ultimately proved right. Regrettably, however, at the time few of my colleagues understood my not wanting to devote my life to it.” •

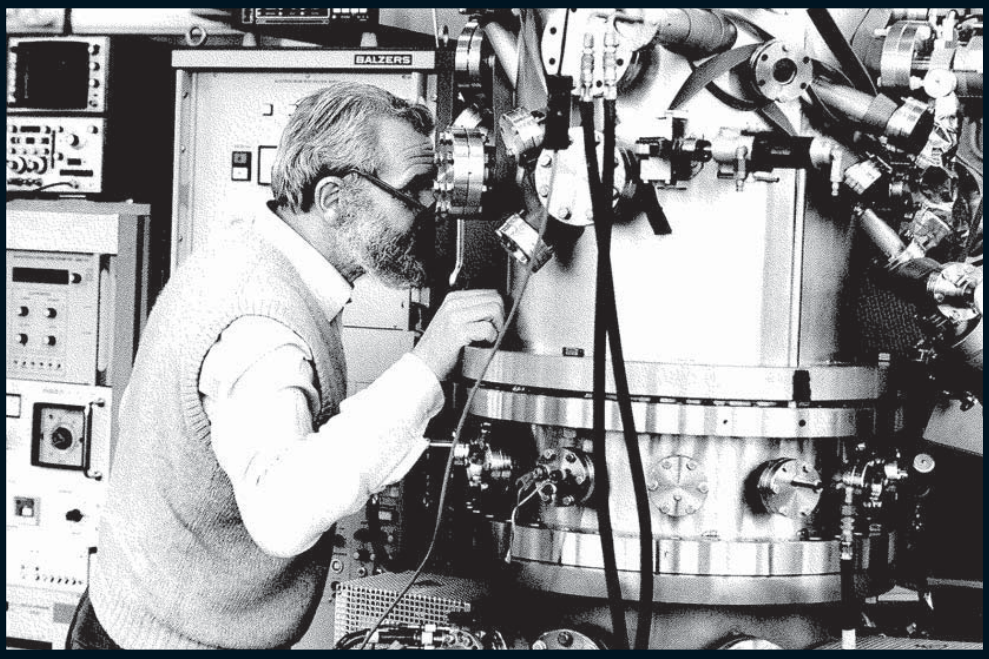
PUBLICATIONS

1949-2009

TOTAL OUTPUT 5007 ARTICLES

EXTREME

THE BEST VACUUM
CHOICE OF PUMP AND CLEANING PROCEDURES



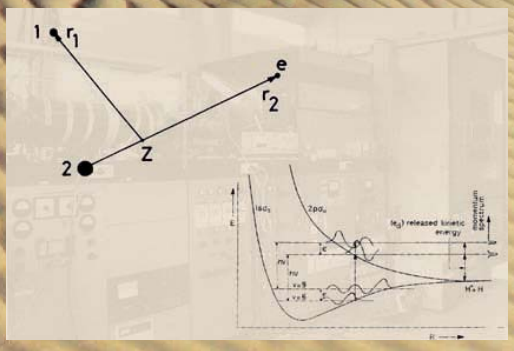
J. Verhoeven, Nederlands Tijdschrift voor Natuurkunde 42, 44 (1976).

The best vacuum at AMOLF ($< 10^{-12}$ mbar) was achieved in 1975 using a combination of a getter ion pump and a titanium sublimation pump. In order to achieve this low pressure, the internal degasification had to be reduced by a factor of 106. This was realized by baking out (outgassing) all the vacuum components in a vacuum oven at 400°C after production. After assembly, the system including pumps was again baked out at 250°C. This procedure had to be repeated each time after aeration.

THE 1970s

The interaction of atomic and molecular beams with surfaces became one of the significant research themes at AMOLF. Material surfaces are manipulated just like a desert whose surface structure is eternally changing due to external influences. Atomic and molecular physics flourished. These were the first years in which the sector was able to reap the benefit of years of investment in developing equipment and measuring techniques in the 1960s. Researchers went increasingly public with their work, in terms of contact with their scientific colleagues and with the business community.

1970…1979



Collision induced dissociation was further developed in the 1970s. In the accelerator in the background different vibrational states can be produced prior to an ion-molecule collision. The figure shows the potential energy diagram of various dissociative states of a hydrogen molecule and the kinetic energy released during dissociation.

HIGHLIGHTS 1970-1979

In the 1970s, the technology for the generation of atomic and molecular beams became so sophisticated that detailed experiments could be carried out in the field f interaction between beams of electrons, atoms and molecules. The interaction of atomic and molecular beams with surfaces also became an important theme. Moreover, new activities in the field of electron beam-plasma interactions also started. The first lasers came into the laboratory. The development of pyrolysis mass spectrometry gave mass spectrometry a new impetus.

1970

Surface physics with 200 kV accelerator

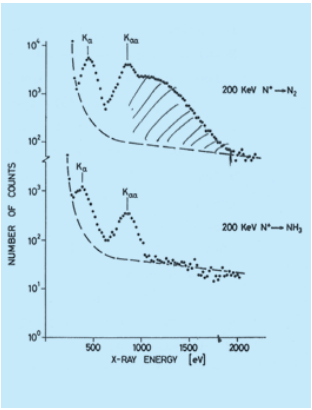
The micro-ammeter shown on the left was the most 'looked at' component of the 200 kV accelerator. The maximum deflection of the ammeter determined the success or failure of an experiment.
The 200 kV accelerator was used for the first 'channelling' and 'blocking' experiments carried out in the 1970s. The latter technique rapidly created a furore under the name of 'ion beam crystallography'. Crystallography research on surfaces and interfaces using this machine yielded about fifteen doctoral theses. One of the highlights was the discovery that the melting of solid substances (usually) begins at the surface.

1972

Molecular X-rays

F.W. Saris, W.F. Van der Weg, H. Tawara and R. Laubert, Phys. Rev. Lett. 28, 717 (1972).

During collisions between heavy ions and atoms, the electrons from the colliding particles form quasimolecular states. These molecular states first became visible as characteristic continuum radiation in the Röntgen spectra of these collisions.

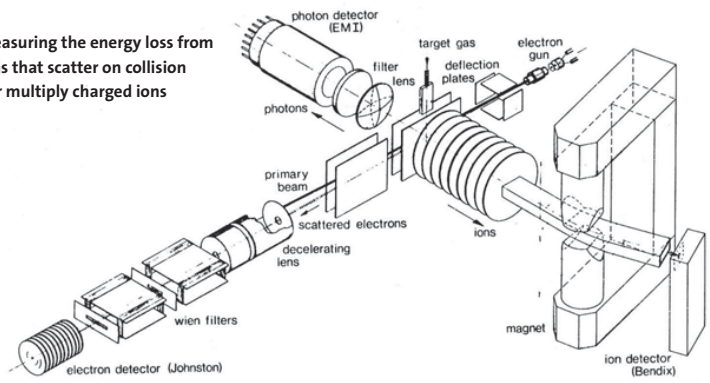


1974

Pyrolysis mass spectrometry

FIRST BIOPHYSICS AT AMOLF
A fully automated pyrolysis mass spectrometer was built on the basis of Henk Meuzelaar's ideas for the rapid identification of bacteria. This was used, amongst other things, for a large numbers of analyses carried out to identify tuberculosis bacteria for the National Institute for Public Health and the Environment (RIVM). As the mass spectrometer was so sensitive, the identification/classification time of six weeks for these slow growers could be reduced dramatically. Subsequently, the instrument was intensively used for the analysis of all sorts of non-volatile materials. The company Hiden launched an adapted version of the instrument on the market.

1971
Set-up for measuring the energy loss from 10kV electrons that scatter on collision with single or multiply charged ions



Cooperation with Philips commences

In the 1970s, Philips was keen to further develop ion implantation for the production of integrated circuits. AMOLF concluded a cooperation agreement with Philips as a result of which Philips researchers could use AMOLF's accelerators until Philips got its own facilities. The Philips group, with all its personnel and resources, was located in the Watergraafsmeer at the Institute for Nuclear Physics Research (IKO). The cooperation continued for more than ten years.

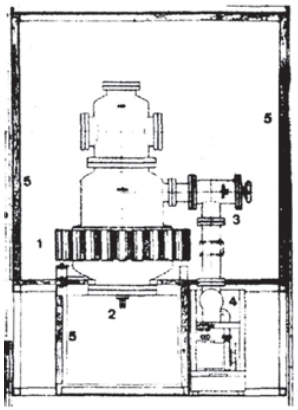
1974 group photo in the big experiment hall:
F.l.t.r. Back row:
Los, Kea, van Veen, Tebra, Visser, v. Deenen, De Jongh, Neuteboom, De Vries
F.l.t.r. Middle row:
Timmer, Hoogervorst, v.d. Hauw, v.d. Zweep, v. Elst, Peeters, Boerboom, v. Dijk
F.l.t.r. Bottom row:
J. Kistemaker, v. Wel, De Haas, v.d. Veen, Tom, Jansen, Akkermans, Sanders, Bannenberg, de Heer, Monterie

1975

Ultra-high vacuum achieved

J. Verhoeven, Nederlands Tijdschrift voor Natuurkunde 42, 44 (1976).

Research on the s urfaces of solid materials aroused a lot of interest at AMOLF in the early 1970s. To this end, ultrahigh vacuum was required, which meant not only the choice of the correct pump, but also the development of techniques to reduce degasification in the materials used. In 1975, AMOLF's 'Vacuum Technical Laboratory', as it was known at the time, succeeded in building a system with a final pressure of 10^{-12} Torr. That could be measured with an 'extractor' gauge developed specially for this purpose by Leijbold Heraeus.



1976

Freezing molecular vibrations

M.M. Hubers, A.W. Kleyn and J. Los, Chemical Physics 17, 303 (1976).

For the first time it was possible to measure the maximum probability of electron transitions by measuring the total active cross section for ion pair formation at high speeds. This was the first step towards understanding harpoon transitions as the introduction to chemical reactions.

Magnetic and electric quadrupole lenses

APPLICATION!

Sensitivity and resolution in classical (magnetic sector) mass spectrometers are highly dependent on the quality of the ion beam. By applying combinations of magnetic and electric quadrupole lenses, the beam quality can be optimized as required. Various lens systems were developed and used to display mass spectra on a 2-D ion detector. These lenses were further developed and applied in a wide variety of commercial equipment in cooperation with the company Jeol.

1978

Laser desorption ionization of biomolecules

M.A. Posthumus, P.G. Kistemaker and H.L.C. Meuzelaar, Analytical Chemistry 985, 50 (1978).

Intact protonized and cationized molecules can be desorbed from a surface by irradiation with short laser pulses. This observation led to a true revolution in the analysis of large biomolecules using mass spectrometry.

Management team (1978):
J. Bannenberg, F.W. Saris, L. Roos, J. Kistemaker, M.J. van der Wiel, J. Los

"I had the graph hanging on the wall in my office as a trophy for years."

Joost Frenken began as a student at AMOLF in 1979 and began his doctoral research in 1982. In 1986 he left the institute for several years to return in 1988 as a group leader, which he remained until 1997. Since then he has worked at the University of Leiden's Kamerlingh Onnes Laboratory.

JOOST FRENKEN

"I asked myself: **HOW DOES A CRYSTAL BEGIN TO MELT?**"

"Phase changes such as melting, freezing and boiling appear to occur precisely at the melting or vaporization temperature. In reality, however, a trigger is always needed for a phase change of this kind: the freezing of water always begins with the formation of a single crystal, boiling with a single gas bubble. In a clean, stable environment, without triggers, freezing can be delayed until far below freezing point. It is, for example, possible for a container of water to remain liquid in the freezer, until you intervene – and then it suddenly freezes very rapidly. Similarly, water can heat up in a microwave oven to far beyond 100 degrees without beginning to boil. As soon as you get hold of it, however, the hot water shoots up in bubbles in all directions, causing the typical microwave accident.

It seems logical that some kind of trigger is also required for the melting of a crystal and that it must also be possible to heat a crystal beyond its melting temperature without it actually melting. Yet, no matter how hard people tried, they did not succeed. It was assumed that the start of the melting process begins below the melting point, yet nobody was able to demonstrate it.

I was in luck because, at AMOLF, I could examine how the melting process of crystals begins by taking measurements with ion beam crystallography. I could count how many layers of atoms had already melted at each temperature. I had already taken the first measurements early in my doctoral research and my doctoral thesis supervisor wanted to know what would happen if I heated lead. So I heated lead, but I did not see the impact of the measurements and shoved them in a drawer. A year and a half later a theoretical lecture jolted me awake. I had indeed measured an effect! Only not very accurately, so the measurements had to be carried out again. I measured all night, together with my supervisor Friso van der Veen who found it so exciting that he wanted to be there too. That graph, on which we had drawn in the measurements, point by point, by hand, hung on the wall of my office as a trophy for a long time. We went home at five o'clock in the morning. The next morning the news had already gone all round the lab: the first layer of atoms of the lead surface had begun to melt fifty degrees below the melting point.

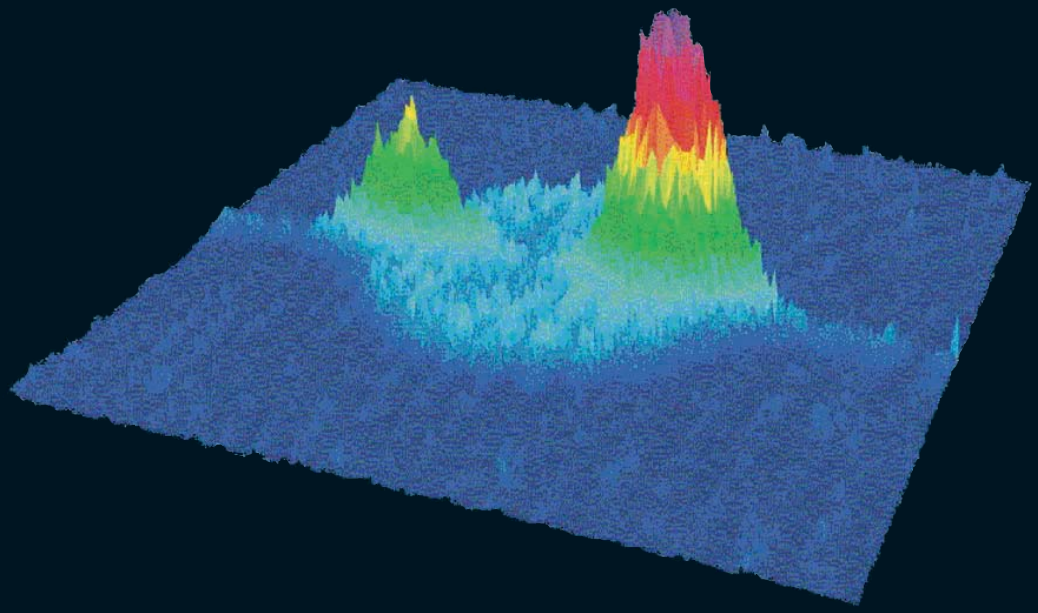
The fact that we had developed the equipment ourselves gave us a big technical advantage and, consequently, an intellectual advantage. We were able to think up new experiments because we had already mastered the technology. There were other groups who tried to do what we did. But if you have difficulty taking a measurement at all, you do not take chances with something as risky as heating lead until it melts.
This focus on instrumentation is typical of AMOLF and it does give the institute a substantial scientific edge. Moreover, it results in more complete scientists. The complete scientist is, in my opinion, a characteristic AMOLF product." •

THE 10 MOST CITED AMOLF ARTICLES

1988-2010

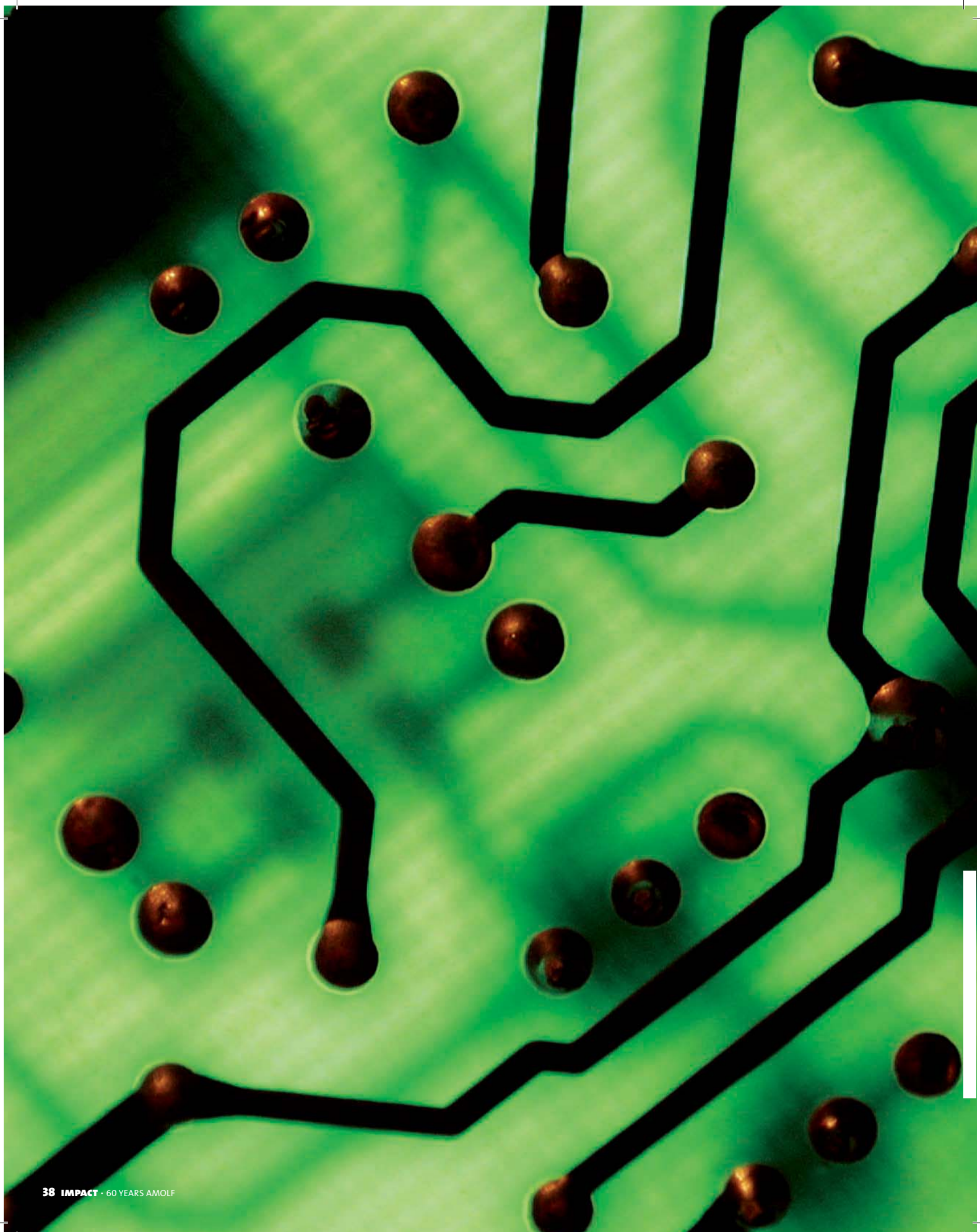
EXTREME

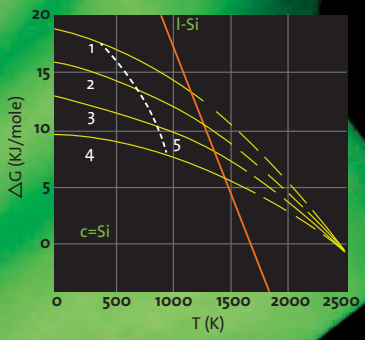
THE COLDEST ATOM
500nK (0,000.000.5K)



C. Buggle, J. Leonard, W. von Klitzing and J.T.M. Walraven, Phys. Rev. Lett. 93, 173202 (2004).

The elastic scattering of atoms at low energy can be measured by bombarding two Bose-Einstein condensates, cooled to a temperature of a couple of hundred nanoKelvin, against one another. The s and d-wave scattering patterns can be made visible by varying the energy of the collision. The researchers showed that the active cross section can be determined accurately with a single photo of the scattering pattern, without knowing the number of colliding atoms. The temperature of the atoms was 500 nK (0.000,000,5 K).





The crystalline, amorphous and liquid forms of Si all play a role in the production of silicon electronic devices. Strangely enough, though, the melting point of amorphous Si was not known. Studies of the melting and solidification of silicon using short laser pulses and calorimetry revealed that amorphous Si has many atomic structures, each with its own melting point.

1980…1989

THE 1980s

The advent of microelectronics meant that there were a great many areas of surface and material physics needing investigation. The research became increasingly international. Despite the aftermath of the cold war, physicists from America, Russia, Japan, China and Europe cooperated closely at AMOLF. Conversely, AMOLF researchers went abroad, as postdoctoral researchers or for a sabbatical, more and more often.

HIGHLIGHTS 1980-1989

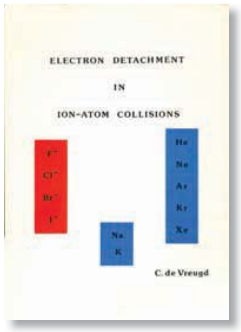
In the 1980s, the institute acquired a strong reputation with its surface physics research. Ion beam crystallography made it possible to determine the atomic structure of surfaces. Furthermore, new materials could be made for a variety of applications, including solar cells, with the newly-developed ion accelerators. After the discovery of the 'poor man's synchrotron', atomic physics concentrated increasingly on processes in extremely strong laser fields and broke many records in this field. In molecular physics, molecular surface scattering and molecular vibration spectroscopy were important topics. Pyrolysis gas chromatography mass spectrometry focused on the characterization and identification of bio-organic substances, amongst other things. The MEQALAC project was successfully completed with the production of an intense beam of 1 MeV N ions for plasma physics experiments.

1980

Molecular vibrations seen on femto-second time scale I

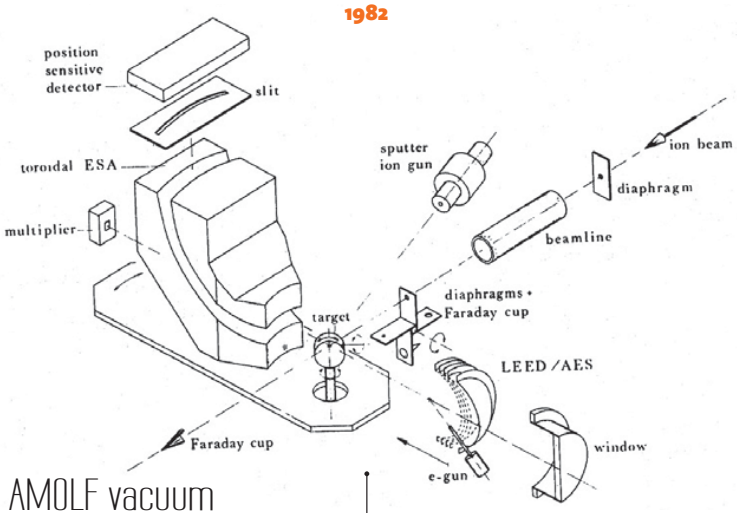
A.W. Kleyn, V.N. Khromov and J. Los, J. Chem. Phys. 72, 5282 (1980).

Oscillations, which were the result of full molecular vibrations during a collision, were seen in a differential active cross section. One of the colliding particles, by way of its ultimate charge state, was used as a probe for ultrafast molecular vibrations.



1980
100e AMOLF-proefschrift
C. de Vreugd: Electron detachment in ion-atom collisions (Universiteit Leiden, 1980)
Promotors: J. Los and J. Kistemaker

1982



AMOLF vacuum courses become a concept

E.P.Th.M. Suurmeijer and J. Verhoeven, Vacuümtechniek; Nederlandse Vacuüm-vereniging (NEVAC) 1989.

Many vacuum courses were organized by AMOLF's 'Vacuum Technical Laboratory' until well into the 1990s. The majority of those attending came from the business sector. These courses trained participants for examinations organized by the Netherlands Vacuum Society (NeVac) which were widely recognized. In the early years a small book, Elementaire Vacuümtechniek (Elementary vacuum technology) written by Piet Rol, was used. Later a more comprehensive and updated textbook was published by AMOLF, which also served as a reference book. The most recent edition still forms the basis for courses at both higher professional (HBO) and university education (WO) levels.

APPLICATION!

Ion beam crystallography

APPLICATION!

J.F. van der Veen, Surface Science Reports 5, 199 (1985).

In the 1970s, the foundations were laid for a powerful new measuring method that was extremely sensitive to the crystal structure of the outermost layer of atoms of solids: medium energy ion scattering (MEIS). MEIS was also the optimum method for measurements on interface structures, surface vibrations and the disorder that, for example, arises in the phenomenon of surface melting. High Voltage Engineering Europa BV marketed a commercial MEIS instrument based on the developments at AMOLF which is still enjoyed by a faithful host of users around the globe.

zz

The Doctorate Factory

In 1986, Janneke Koelewijn, a journalist for the Dutch weekly Vrij Nederland (VN), spent a month at AMOLF in order to write the VN supplement 'De promotiefabriek' (The Doctorate factory).

Earning one's doctorate at FOM entailed searching for the vibrations of the atom day and night for four years!

1983

Two-particle detector with temporal and spatial resolution

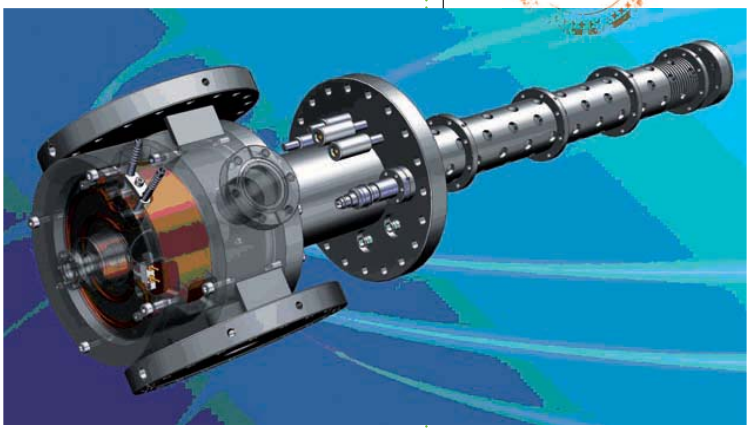
D.P. de Bruijn and J. Los, Rev. Sci. Instrum. 52, 1020 (1982).

The micro-channel plate was expanded, by Joop Los, with a separate read-out device that enabled measurements of correlated rapid keV particles with a spatial resolution of 60 µm and temporal measurements of better than 1 ns. This detector resulted in a revolution in translation spectroscopy by raising the counting speed and expanding its application to include fast neutrals. It was the main feature in a lot of AMOLF doctoral studies. The detector and the principle of kinematic imaging inspired dozens of groups all over the world.

The 2π 'Kruit' spectrometer

P. Kruit and F.H. Read, J. Phys. E: Scient. Instrum. 16, 313 (1983).

In 1983, Pieter Kruit and Frank Read invented a new type of time-of-flight (TOF) electron spectrometer: a 'magnetic bottle' whose field leads all the electrons from a target in a 2 π solid angle to the detector. The first measurements carried out with this detector on multiphoton ionization of Xe attracted so much attention that a lot of organizations wanted one. AMOLF then transferred the rights to a small laser company in Asten (Noord Brabant), which sold almost 100 of these spectrometers within a number of years.



1984

Proton irradiation of CH_4 led to sputtering of large molecules

A.E. de Vries, R. Pedrys, R.A. Haring, A. Haring and F.W. Saris, Nature 311, 39 (1984).

A beam of protons with an energy of several keV directed at a frozen methane surface releases large hydrocarbon molecules from the surface, which subsequently move freely in the vacuum. This work had implications for the study of planets, where these processes may also occur.

Cross section for charge exchange with stripped ions

D. Dijkkamp, D. Ciric and F.J. de Heer, Phys. Rev. Lett. 54, 1004 (1985).

The cross section for charge exchange in collisions of atomic hydrogen and C^{6+}, N^{7+} and O^{8+} ions was measured. The results corresponded extremely well with theoretical calculations and were important for plasma diagnostics.

Multiphoton ionization in strong radiation fields

H.G. Muller and A. Tip, Phys. Rev. A 30, 3039 (1984).

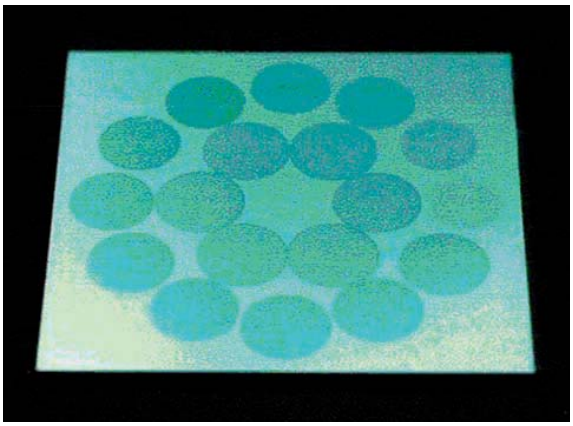
In the multiphoton ionization of atoms, the quantity of photons absorbed can be derived from the energy of the electrons emitted. Experiments carried out by Van der Wiel et al. showed that the first energetically possible peaks that corresponded with an energy that was just enough to overcome the ionization potential were missing from the spectrum. A theoretical explanation of this effect was found in details concerning the vector potential in the Hamiltonian. This work led to the authors being awarded the Teylers Medal.

1984

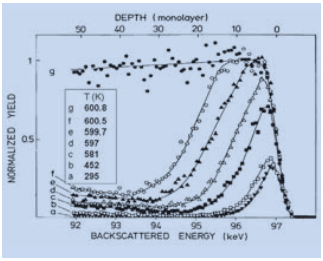
Explosive crystallization of amorphous silicon

W.C. Sinke and F.W. Saris, Phys. Rev. Lett. 53, 2121 (1984).

Silicon formed the raw material for most electronic equipment and solar cells 25 years ago and it still does. The amorphous and crystalline forms are the most significant ones and it is very important that we understand the transition between the two. Because amorphous silicon contains more energy than crystalline silicon, the transition can take place explosively after 'a nudge' with a laser pulse.



1985



Surface melting of lead

J.W.M. Frenken and J.F. van der Veen, Phys. Rev. Lett. 54, 134 (1985).

There had, for some time, already been predictions that melting begins at the surface well below the normal melting point. This would explain the usual absence of spontaneous overheating of solids above the melting point. The first convincing evidence to support this significant phenomenon came from ion scattering measurements at the (110) surface of lead.

Jacob Kistemaker prize

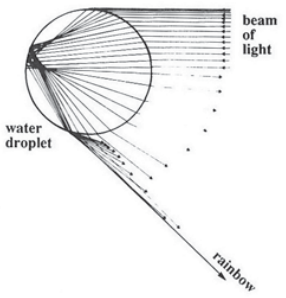
In 1986 the Jacob Kistemaker Prize was awarded to Frans Saris and Friso van der Veen for their work on surface physics. Wim Sinke (1992) and Joost Frenken (2007) were also to win this prize later.

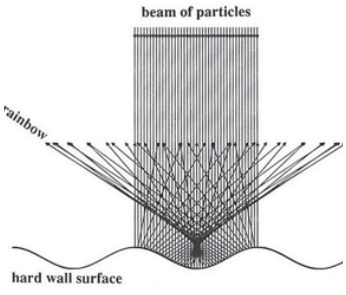
1986

Harpooning sticks molecules to a surface

P. Haochang, T.C.M. Horn and A. W. Kleyn, Phys. Rev. Lett. 57, 3035 (1986).

For the first time, harpoon transitions were seen that suggested that charge transfer from a surface to a molecule forms the first step in the chemisorption of molecules on surfaces.

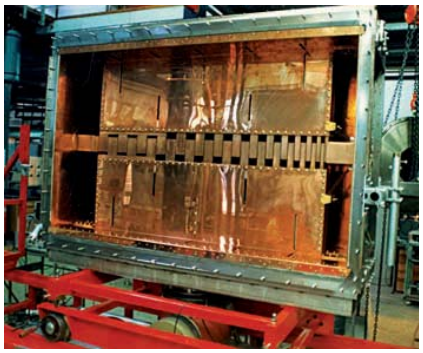




IN THE NEWS

The opening of the accelerator facility

1987
The MeV accelerator facility was opened with a concert for cello and two accelerators, composed by Frances-Marie Uitti.



MEQALAC: Multiple Electrostatic Quadrupole Array Linear Accelerator

R. Wojke et al. Nucl. Instr. Meth. A 300, 25.

In the MEQALAC accelerator developed at AMOLF, multiple parallel N^+ ion beams were accelerated by using 32 radio frequency accelerating sections connected in series, operated at 25 MHz. The very intense ion beams were focused through a set of miniature electrostatic quadrupole lenses. The accelerator was used to accelerate 1 mA N^+ beams to 1 MeV. The accelerator was developed to serve as an injector for plasma physics experiments.

1987

Atoms in strong radiation fields

M. Pont and M. Gavrila, Phys. Rev. Lett. 65, 2362 (1990)

Gavrila and Pont predicted that the wave function of the electron in hydrogen forms a new stable macroscopic state in super intense ultra-short laser pulses: a doughnut for circularly polarized laser light and a dumbbell for transversely polarized light.

Lap time of the electron measured

A. ten Wolde, L.P. Noordam, A. Lagendijk, and H.B. van Linden van den Heuvell, Phys. Rev. Lett. 61, 2099 (1988).

The classical concept is that the electron rotates around a positive atomic nucleus. In quantum mechanics, an electron orbit is represented by a delocalized wave function. By adding up waves (eigen states) the electron becomes localized again after all and the packet has a lap time that equals the classical lap time. With the aid of ultra-short laser pulses, researchers succeeded in experimentally determining this lap time for the first time. The headline in the Belgian press at the time was "The Dutch are seeing things" (Hollanders zien ze vliegen).

1988

APPLICATION!

Shell builds solar cell factory with AMOLF technology

The Shell subsidiary R&S in Helmond built a production line for polycrystalline silicon solar cells. Various process steps developed at AMOLF were applied in the R&S production process.

MeV heavy ion accelerator

A. Polman et al., Nucl. Instr. Meth. B 37/38, 935 (1989).

APPLICATION!

The surface and materials research implemented at AMOLF in the 1980s required thicker and thicker surface layers. A 1 MeV heavy ion accelerator was developed in cooperation with High Voltage Engineering Europa BV.
The new features of this device were: an ion beam exchange system, with which the source could be replaced without opening the accelerator tank, and a specially designed accelerator tube that did not produce any radiation. This accelerator was used up until 2002 and resulted in more than 250 publications and 25 doctoral theses.

DAAN FRENKEL

"I asked myself: **HOW DO CRYSTALS FORM?**"

Daan Frenkel worked at AMOLF from 1987 to 2008, first as a group leader and later also as a departmental head and member of the management team. He used numerical methods for research into how order arises from chaos. Frenkel has worked at Cambridge University since 2008.

In the physics of simple systems, theory and experiment are sufficient to understand most phenomena, but for more complex systems it is extremely difficult to make quantitative theoretical predictions. If, subsequently, the experiment does not correspond with the theory, it is impossible to determine whether the mistake is in the theory itself, in the approximation you have had to make, or in the experiment. Strictly speaking, experiments are never wrong: you measure what you measure – there is, however, sometimes a problem with the interpretation of measurements. Numerical simulations may then provide the solution. Simulations are no more difficult than calculating things by hand, but because a computer is many times faster, you can get it to repeat a calculation many times. Simulations are, therefore, a sort of experiment in the computer. They give a prediction of the outcome of a real experiment.

My numerical background made me the odd man out at AMOLF. In those days, simulations were carried out only when interpreting experiments, never as an objective in themselves. At the time, the institute focused primarily on experiments, and atomic and surface physics made up the bulk of the research. My research was

"Simulations enable you to 'imitate' experiments that are not yet technically possible."

in line with the experimental research into liquid crystals and polymers being carried out by Wim de Jeu, amongst others. I was interested in how spontaneous organization takes place in disorganized or chaotic materials from the numerical point of view and that is precisely what happens in the formation of a crystal.

The great thing about simulations is that you can also simulate experiments that are not yet technically possible. You can, for example, investigate the order in materials that have not yet been made. Simulations enabled us to make predictions that were only substantiated by means of experiments ten or fifteen years later. One of the areas that our simulations clarified was the influence of charge on the speed of crystal formation. Our calculations also gave us an understanding of how to speed up the crystallization of proteins.

I have always gratefully availed myself of the good scientific atmosphere at AMOLF and of the opportunities provided to develop totally new innovations. In my case, this did not involve complicated technical equipment, but we were given the time to invest in completely new methods of calculation. In fact, we made a numerical device and that meant that we could actually make good predictions on the stability of crystals and the speed with which they form."•

AMOLF FACTS AND FIGURES

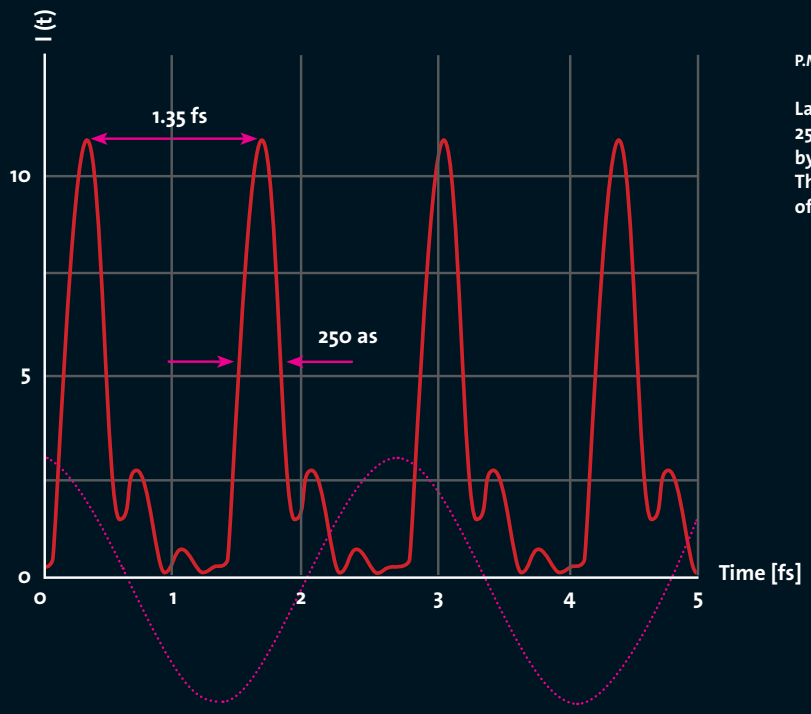
AMOLF'S BUILDINGS

1960 KRUISLAAN 407 **1970** EXTENSION **1986**

2009 SCIENCE PARK 104

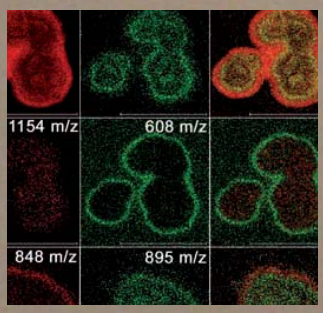
EXTREME

THE SHORTEST LASER PULSE
250 ATTOSECONDS (0,000.000.000.000.000.25 S)



P.M. Paul et al., Science 292, 1689 (2001)

Laser pulses lasting only 250 attoseconds were produced by generating high harmonics. This enabled the temporal study of the movement of electrons.

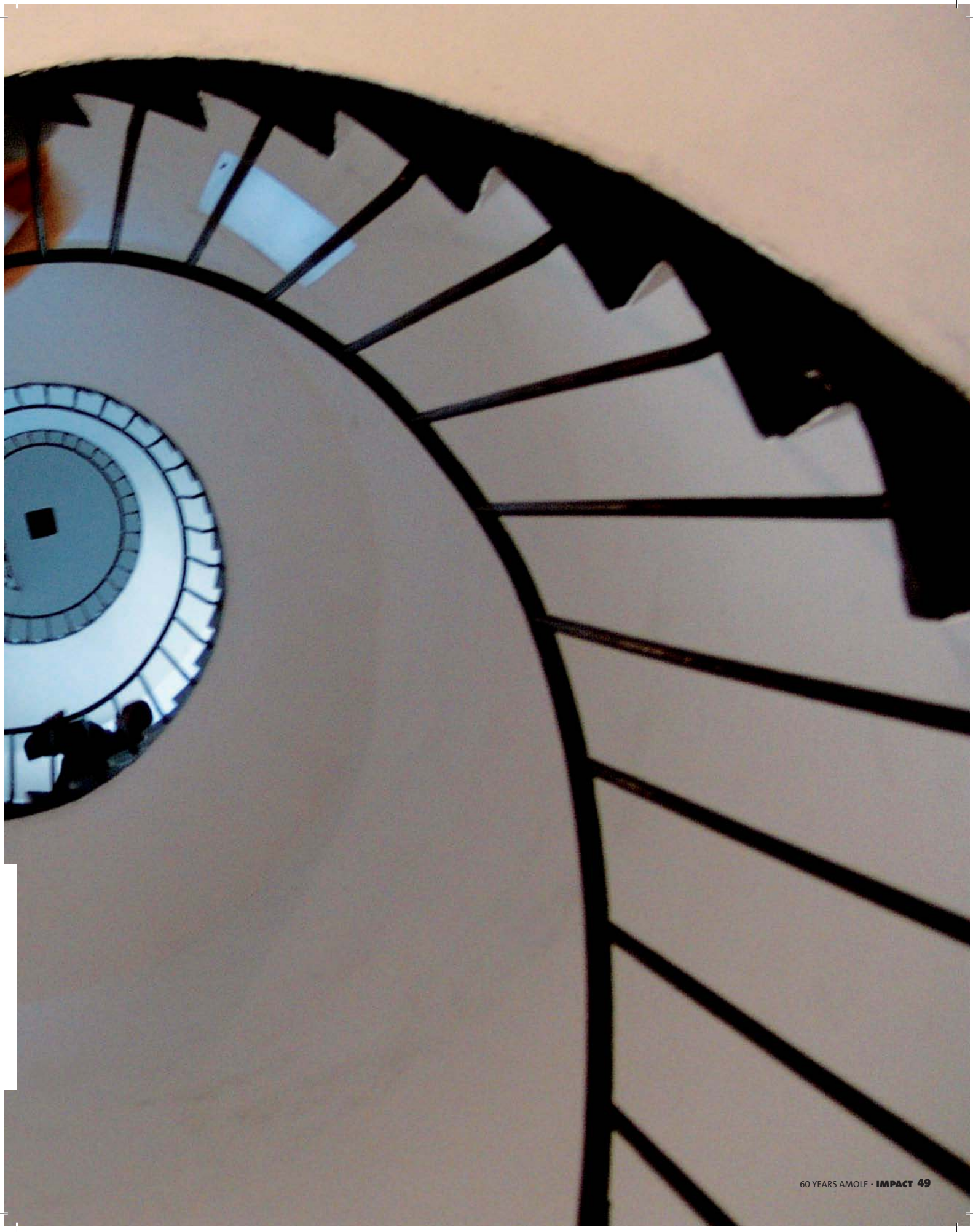


Illustrations of proteins made using a mass spectrometer.

1990…1999

THE 1990s

The physics of soft materials emerged as a new theme for fundamental research with important applications and AMOLF started research into the physics of living systems. First it focused on a few biomolecules such as DNA, shown schematically here, and later on more complex systems. AMOLF had a very dynamic character: two thirds of the employees had a temporary appointment and moved on after a couple of years. Research became increasingly international. More and more foreign doctoral students were also coming to the Netherlands to carry out research here.



HIGHLIGHTS 1990-1999

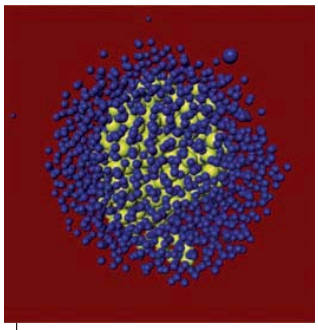
After the discovery of surface melting, surface physics concentrated increasingly on the dynamics of surfaces with the aid of scanning probes and x-ray scattering. The entire successful solar cell programme moved to the Energy Research Centre of the Netherlands (ECN) in Petten. Research into soft condensed matter and computer physics, which had already started in the 1980s, took off at this point. The first experiments in the physics of biomolecular systems began. Atomic and molecular physics on extremely short time scales became possible in very strong (laser) radiation fields. Quantum gases formed a new theme at the institute, as did optoelectronics and ultrafast dynamics in condensed matter. Mass spectrometry began to focus on the molecular causes of ageing processes in paintings.

1991

Light is slowed down substantially in scattering media

M.P. van Albada, B.A. van Tiggelen, A. Lagendijk, and A. Tip, Phys. Rev. Lett. 66, 3132 (1991).

On the basis of experiments and theory, the AMOLF group discovered that the propagation of light could be greatly delayed (by up to a factor of ten) in scattering media. This discovery initially met with a great deal of resistance from the scientific community, particularly because it concerned an example in which electrons and light behave differently. Now it is seen as a milestone which has also been confirmed for other classical waves, such as sound.



Phase behaviour of chain molecules predicted

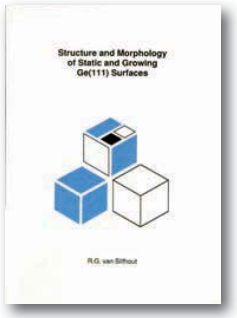
D. Frenkel, G.C.A.M. Mooij and B. Smit, J. Phys. Condensed Matter 3, 3053 (1991).

In the period 1960-1970, numerical techniques were developed for predicting the phase behaviour of inert gases and small molecules. These techniques could not, however, be used for larger molecules. The new method developed at AMOLF in 1991 is still the standard method for the prediction of phase behaviour of chain molecules. The method was subsequently used by other researchers for various purposes, including designing new catalysts.

Vibration constant OF O^{2-}_2 molecules

W.J. van der Zande, Chem. Phys. 157, 287 (1991).

It is a known fact that a molecule can be ionized, but it is rather surprising that you can take two electrons out of a molecule without it immediately exploding. Joop Los's two-particle detector enabled the study, and the determination of the characteristics, of a very tiny fraction of O^{2-}_2 in a beam of O^+. For a very short period, this class of molecules was seen as the beginning of a very high-energy fuel; it formed one of AMOLF's research themes for a couple of years.



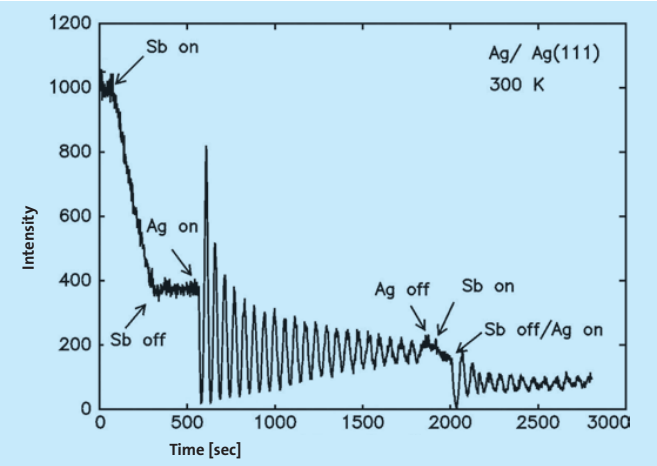
200th AMOLF PhD thesis
R.G. van Silfhout: Structure and morphology of static and growing Ge(111) surfaces (Universiteit Leiden, 1992)
Promotor: J.F. van der Veen

AMOLF's solar cells go to ECN

W.C. Sinke et al.

After a number of years of pioneering research on solar cells in the 1980s, the programme was transferred to the Energy Research Centre of the Netherlands (ECN) in 1990. Themes, equipment and researchers moved. At the new location the research was able to develop further and broaden to include technology and applications, which it did very successfully. Today, 85 people work on all aspects of photovoltaic conversion at ECN, and the department plays an international. ECN has various world records relating to solar panel performance to its name.

1992

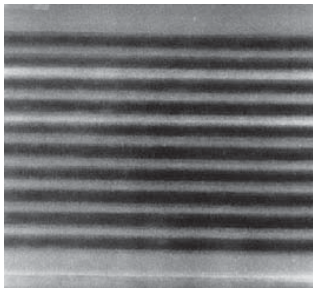


X-ray mirrors with ultra-smooth multilayers

APPLICATION!

E.J. Puik, M.J. van der Wiel, H. Zeijlemaker and J. Verhoeven, Appl. Surf. Sci. 47, 251 (1991).

Multilayers of, for example, Ni/C and W/C are efficient mirrors for Röntgen radiation. For optimum reflection, the interfaces must be smooth to within tenths of nanometres. The surface roughness that forms during the growth of the layers could be polished away with the aid of inert gas ions. This yielded three times the reflection for multilayer mirrors for irradiation with a wavelength of 3.2 nm. The research into x-ray multilayer mirrors was moved to the FOM Institute Rijnhuizen in the course of the 1990s. It subsequently laid the basis for a big Industrial Partnership Program (IPP) between FOM and Zeiss. This, in turn, led to the successful application of these mirrors in the latest ASML EUV scanner, in which 13.6-nm radiation is used for lithography.



'Soap' for smooth crystal growth

H.A. van der Vegt, H.M. van Pinxteren, M. Lohmeier, E. Vlieg and J.M.C. Thornton, Phys. Rev. Lett. 68, 3335 (1992).

The world's first in-situ measurements of crystal growth using x-ray diffraction were realized by AMOLF in 1988. Four years later the researchers discovered by chance, in the last four hours of a two-week experiment full of setbacks, that antimony causes silver to grow much more smoothly on the (111) surface.

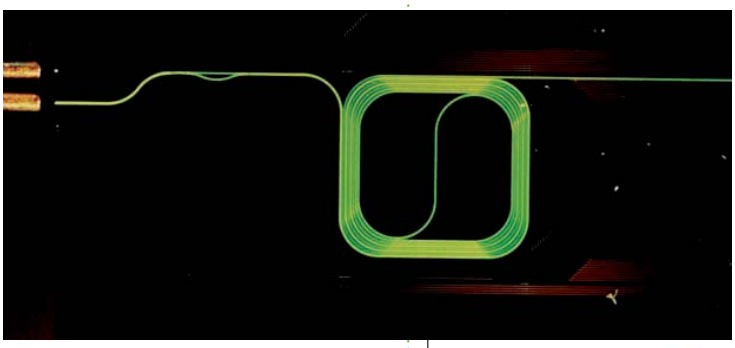
Nucleation speeds predicted

J.S. van Duijneveldt and D. Frenkel, J.Chem.Phys. 96, 4655 (1992).

Nucleation may be exceptionally infrequent (it may occur at intervals of hours, days, months or years) which makes direct simulation of this phenomenon complex. Early in the 1990s, a technique was developed at AMOLF that enabled the direct calculation of nucleation barriers. This work (and the many AMOLF publications which succeeded it) resulted in a revival of the study of crystal nucleation.

HIGHLIGHTS 1990-1999

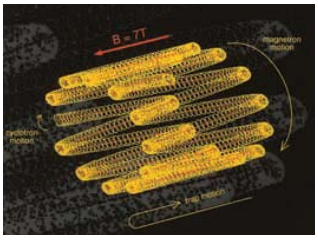
1993



Stabilization against ionization

M. Pont and M. Gavrila, Phys. Rev. Lett. 65, 2362 (1990).

Theoretical work by Gavrila et al. predicted that atoms would be stable against ionization in an extremely intense laser pulse. This idea, which goes against intuition, was experimentally confirmed for the first time with neon ions in a 100-fs laser pulse with an intensity of 10^{14} W/cm^2.



1995
Ion movement in the new Fourier Transform Ion Cyclotron Mass Spectrometer

1996

Miniature erbium light amplifier

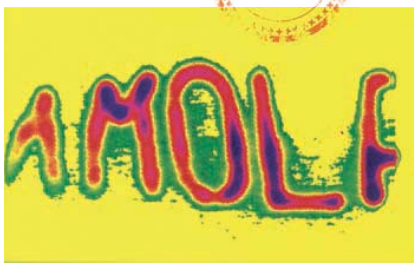
G.N. van den Hoven, A. Polman, C. van Dam, J.W.M. van Uffelen and M.K. Smit, Appl. Phys. Lett. 68, 1886 (1996).

AMOLF started research on integrated optics. A 600-nm-thick Al_2O_3 optical waveguide on a Si substrate was doped with erbium ions using the MeV ion accelerator. Researchers were able to amplify a signal at 1.5 micrometres by a factor of two with a pump laser. Light amplifiers on silicon are important because they connect optics and microelectronics. This structure is still the world's smallest erbium doped optical amplifier; it was later transformed into a product by the American company Symmorphix.

When does an electron leave an atom?

M. Lankhuijzen and L.D. Noordam, Phys. Rev. Lett. 76, 1784 (1996).

An atom that absorbs a photon can ionize. But how long does it take before the electron actually leaves the atom after it has absorbed the photon energy? Using a streak camera developed in-house, AMOLF researchers were the first to measure when the electron escapes from the atom: it took a few picoseconds after all. The streak camera technology was patented and used to build a far-infrared detector with a resolution of only 2 oscillations of the electromagnetic field.



Professor Muller giving a lesson in keeping things in equilibrium

April 1997
Harm Geert Muller giving a physics lesson in the André van Duin show.

1997

Mechanism of protein crystallization

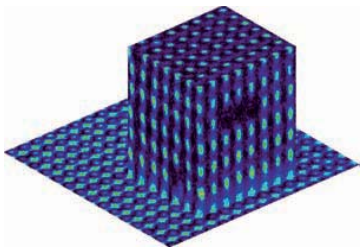
P.R. Ten Wolde and D. Frenkel, Science 277, 1975 (1997).

Many protein solutions show remarkable phase behaviour: a supersaturated solution demixes spontaneously in a concentrated and diluted phase. Calculations showed that the speed of crystal nucleation shoots up, often above the critical point of the metastable demixing curve. This phenomenon has significant practical consequences for choosing the optimum conditions for growing protein crystals for x-ray diffraction.

The reactivity of a surface changes within an Ångstrom

D.A. Butler, B. Berenbak, S. Stolte ea dA. W. Kleyn, Phys. Rev. Lett. 78, 4653 (1997).

A surface that is covered with hydrogen atoms acts as a perfect mirror for incident NO molecules, but it also intercepts half of these molecules. It could be concluded that the reactivity of an Ru surface covered with hydrogen is cancelled locally very close to the hydrogen.



Colloidal crystals grow on a structured surface

A. van Blaaderen, R. Ruel and P. Wiltzius, Nature 385, 321 (1997)

Epitaxial crystal growth comprises the growth of a crystal of a particular material on a single crystal of another material with approximately the same lattice constant. This method can be used to grow crystals that do not even have an equilibrium structure. We applied this technique, which is now called colloidal epitaxy, to the growth of colloidal particles.

1998

Magneto-optical trap as source for cold atoms

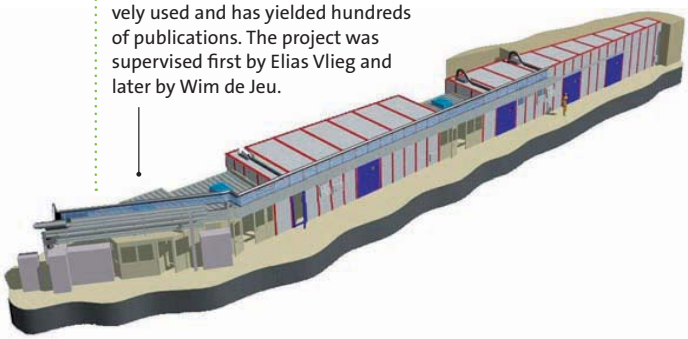
K. Dieckmann, R. Spreeuw, M. Weidemuller and J.T.M. Walraven, Phys. Rev. A 58, 3891 (1998).

Optical cooling in two dimensions appeared to be eminently suitable for the construction of compact, clean, intense sources of cold atoms. The first source of this type was built at AMOLF. .

DUBBLE beam line at ESRF

M. Borsboom et al. J. Synchr. Rad. 5, 518 (1998).

Between 1994 and 2000, AMOLF's complete technical infrastructure was used to design and realize the 'DUtch Belgian BeamLinE' (DUBBLE) at the ESRF synchrotron in Grenoble. This project entailed the design of the entire layout and production of optical elements and parts of the experimental equipment. The DUBBLE beam line is still extensively used and has yielded hundreds of publications. The project was supervised first by Elias Vlieg and later by Wim de Jeu.



BART NOORDAM

"I asked myself: **WHEN DOES AN ELECTRON LEAVE AN ATOM?**"

Bart Noordam carried out his doctoral research at AMOLF between 1987 and 1990. He returned in 1992 as a group leader and later became a department head, which he remained until 2000. From 2002 to 2005 he was the fifth director of the institute. Noordam is currently the Dean of the Faculty of Science at the University of Amsterdam.

"If you fire light with the right amount of energy at an atom, an electron can absorb the energy and use it to leave the atom. This phenomenon, known as the photo-electric effect, has been known since Einstein's time. However, I wondered precisely when the electron left the atom. Is that directly after the absorption of the photon energy, or 'a little while' later? I bore the latter possibility in mind because during my doctoral research I had taken measurements on the 'lap times' of electrons. I therefore knew how long it takes for an electron to complete its orbit around the atomic nucleus.

Actually it was a simple question, but it had never been asked before. Moreover, it was difficult to answer. Research on electrons is, in fact, almost always carried out using light. However, a free electron cannot absorb light and consequently you cannot see it! At AMOLF I had the opportunity to design and make equipment with which I could accurately determine the time that electrons shoot off. We did so by deflecting the electrons and then detecting them.

It appeared that, after absorbing photon energy, electrons sometimes 'fly' three or more orbits before leaving the atom. They may even make ten laps before doing so. The precise moment at which the atom leaves the atom depends, amongst other things, on the characteristics of the atom and the energy of the photon. This discovery opened up an entire new arsenal of areas for research. I was almost unable to measure quickly enough to see what I wanted to see.

We were lucky that the electron hung around for a while before shooting off. I compare it with looking for oil; then too, you hope to find a field that you can enjoy for a long time. If we had discovered that the electron shoots off immediately, we would have known the answer, but it would not have been nearly as interesting. Now our research had opened up a rich source of all sorts of things, including a patent on the IR streak camera and various promising areas of research.

Because we had developed our equipment ourselves, we continually led the way in these research fields. That applied not only to my group, but to the institute as a whole. The atmosphere of cooperation at AMOLF was very important here. At lease half of the hundred or so AMOLF articles published in my name were realized in cooperation with other groups." •

"We were lucky that the electron hung around for a little while."

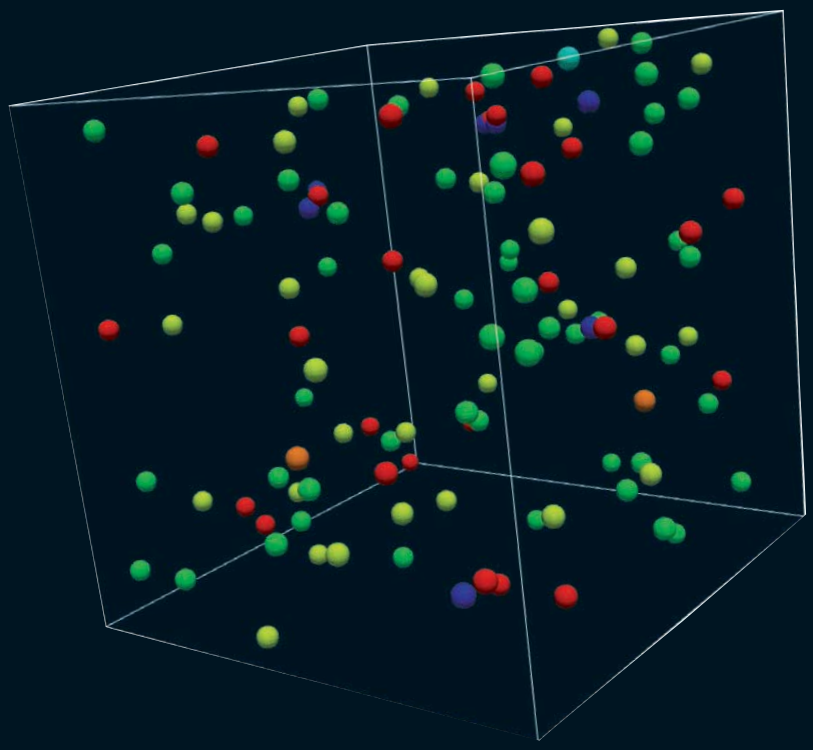
AMOLF's PROFESSORS

(FORMER) GROUP LEADERS AND DOCTORAL STUDENTS AND THE UNIVERSITIES TO WHICH THEY ARE OR WERE ASSOCIATED.

EXTREME

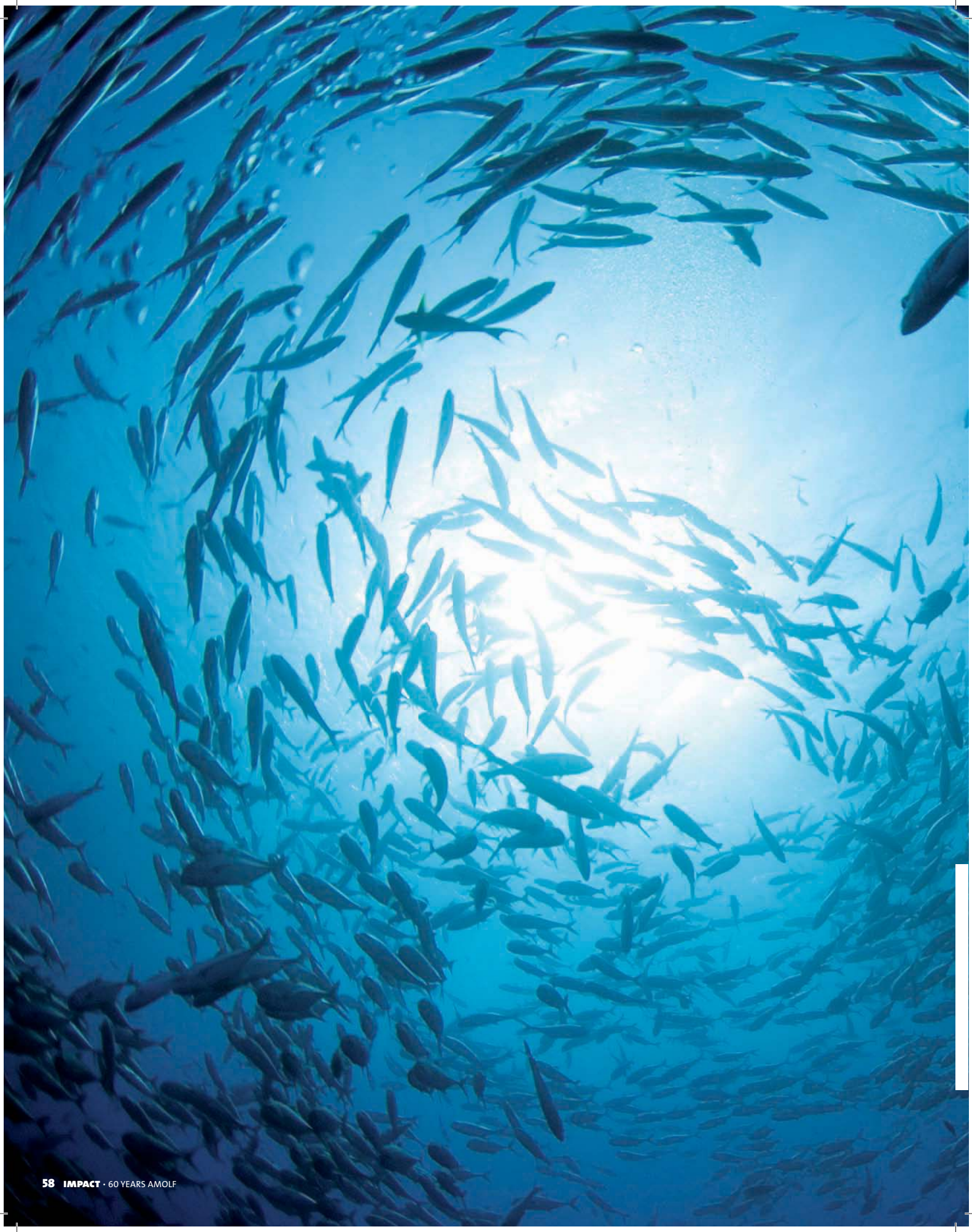
THE FASTEST ALGORITHM

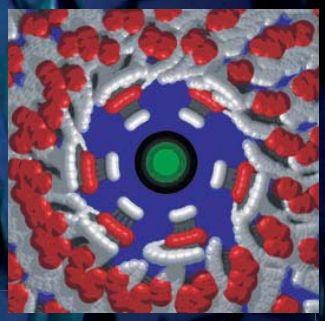
SIMULATING BIOCHEMICAL NETWORKS AT THE MOLECULAR LEVEL



J. S. van Zon and P. R. ten Wolde, Phys. Rev. Lett. 94, 128103 (2005).

Biochemical networks are the analogue computers of life. An algorithm has now been developed to simulate this kind of network, at the molecular level, which is many orders of magnitude faster than existing numerical techniques. This has made it possible to simulate large biological systems.





The structure and dynamics of water were determined using ultrafast laser techniques.

2000…2009

THE BEGINNING OF THE 21TH CENTURY

The emergence of nanotechnology. Now that manufacturing and measuring techniques are growing in sophistication, the nanoscale has come into the picture. Biomolecular physics is creating a distinct profile for itself as a new research area. Science is becoming more and more multidisciplinary: physicists, chemists and biologists cooperate increasingly and new research areas arise at the interfaces between disciplines. Researchers play a larger role in the societal debate. Society asks ever more explicitly about the application-potential of research and the concept 'valorization' (knowledge transfer to society and industry) comes into vogue.

HIGHLIGHTS 2000-2009

At the beginning of the 21st century, AMOLF repositioned itself once more. It focused on two main themes, the seeds of which had already been sown in the 1990s: the physics of biomolecular systems and nanophotonics. Quantum gases, atomic and molecular physics moved to various universities and the art research was concluded. Mass spectrometry concentrated on imaging for biomedical applications. Work on the ultrafast dynamics of molecules addressed biophysical matters more and more. The transfer of knowledge to society and cooperation with Dutch and other European universities grew in importance. Various research groups work together on fundamental research on solar cells.

2000

Spin-off surface preparation company

APPLICATION!

The preparation of clean, smooth surfaces was essential for the surface physics research at AMOLF. Research technician René Koper had specialized in this and received requests from all over the world to prepare crystals and other surfaces. In 2000, he started his own company. Surface Preparation Laboratories (Zaandam) is now a successful company that provides services for domestic and foreign companies and institutes.

Palladium particles move across a TiO_2 surface

M.J.J. Jak, A. van Kreuningen, C. Konstapel, J. Verhoeven and J.W.M. Frenken, Surface Science 457, 295 (2000).

Metallic particles on a ceramic carrier form a catalytic system that is applied in the chemical process industry. The activity of such a system decreases after a certain period of time. This is often attributed to the growth of the particles due to the diffusion of atoms over the surface or to the migration of complete clusters. It was demonstrated, using a variable temperature (video speed) scanning tunnelling microscope (STM), that palladium particles of ≈ 2 nm in size move, as a whole, across a TiO_2 (110) surface.

2001

MOLART applied in the art world

APPLICATION!

The MOLART programme examined aspects of ageing in paint and varnish on paintings and polychrome images using mass spectrometry and chemical microscopy. MOLART and the follow-up programme 'De Mayerne' were formally ended with a symposium in 2006. The researchers in this program have found their way at art research establishments and museums, and in education and the chemical industries. Research is carried out for museums and art restorers in the Netherlands and abroad with spin-off companies set up by MOLART researchers. Recent projects have involved paintings by Vermeer, Jordaens, Rothko and Rembrandt, for example.

Prediction of crystal nucleation

S. Auer and D. Frenkel, Nature 409, 1020 (2001).

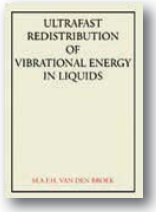
Researchers succeeded in predicting the speed of crystal nucleation of a simple and well-characterized model system, that is, colloidal 'hard spheres', using numerical techniques developed at AMOLF. These calculations showed that the theory failed to correspond with the experiment (which could not actually be tested at that point) to the degree that had been presupposed.

2002

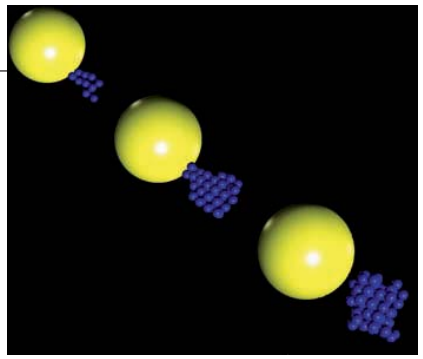
Bose-Einstein condensation out of thermal equilibrium

I. Shvarchuck, C. Buggle, D. Petrov, K. Dieckmann, M. Zielonkowski, M. Kemmann, T. Tiecke, W. von Klitzing, G. Shlyapnikov and J.T.M. Walraven, Phys. Rev. Lett. 89, 270404 (2002)

This experiment showed that Bose-Einstein condensates are formed if the condensation condition is met locally. This type of condensate shows strong phase fluctuations which can be measured by focusing the matter wave and measuring the magnitude of the focus.



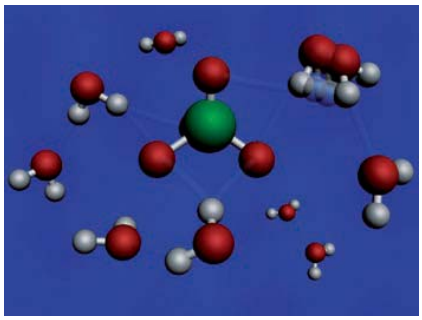
300th AMOLF PhD thesis
M.A.F.H. van den Broek: Ultrafast redistribution of vibrational energy in liquids (University of Amsterdam, 2002)
Promotor: H.J. Bakker



Opening of the Amsterdam NanoCenter

The opening of an ultramodern clean room in 2003 gave AMOLF the use of state-of-the-art nanofabrication techniques such as electron beam lithography, optical lithography, focused ion beam milling and soft lithography. These facilities are essential for research in the fields of nano-photonics and biomolecular physics.

2003



Water becomes slow around ions

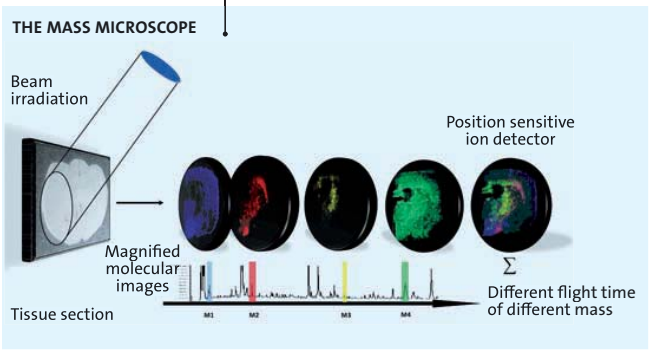
M.F. Kropman, A.W. Omta and H.J. Bakker, Science 291, 2118 (2001)

Around 70% of the water on earth and in our bodies is salt water, that is, water with a high concentration of dissolved ions. The effect of ions on water was investigated with mid-infrared light pulses with a duration of ~100 femtoseconds. The result of this research is summarized in the above 'photo' of water around a ClO_4^- ion which illustrates that water shows much slower hydrogen bridge dynamics and rotation dynamics around an ion than water molecules in bulk water.

2004

Mass microscope

The mass microscope developed at AMOLF uses stigmatic ion optics to make direct images of biomacromolecular ions of tissue surfaces. The mass microscope uses time-of-flight mass spectrometry for molecular identification and laser desorption techniques to release intact molecular ions, such as peptides, proteins and DNA, from surfaces. These techniques enable the rapid and detailed mapping of the molecular morphology of tissue cross sections without specific molecular labels.



2005

Molecular machines flashed

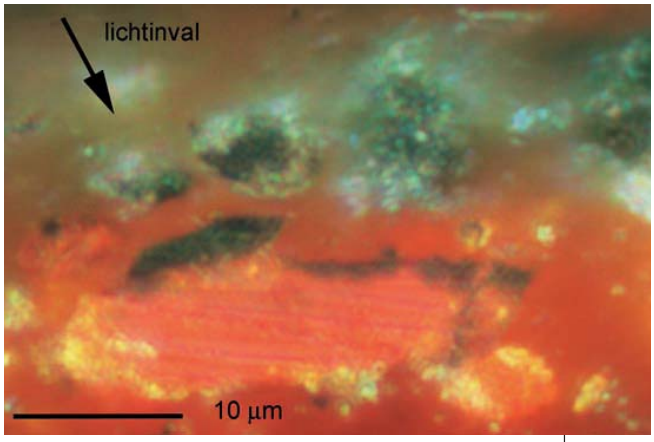
O.F.A. Larsen, P. Bodis, W.J. Buma, J.S. Hannam, D.A. Leigh and S. Woutersen, Proc. Natl. Acad. Sci. USA 102, 13378 (2005).

Molecular machines are not only small, they move extremely fast too. This makes it difficult to show their action. AMOLF researchers managed to 'flash' a molecular machine with two short infrared light pulses, so that the movement of the machine could be followed with a temporal resolution of 0.000.000.000.001 s.

New Light

In 2007, the NRC Handelsblad, a Dutch daily newspaper, published a full-page article on the nanophotonics research at AMOLF, entitled 'New Light'.

Excerpt:
Welcome to the world of New Light. Thanks to nanophotonics, we can catch light in a box, chaos can be put to good use, we can construct minuscule lasers and we know that a surprising amount of light passes through a small gold sieve. Here is a tour.



The blacks of vermillion

K. Keune and J.J. Boon, Anal. Chem. 4742 (2005)

The black crust on vermillion (HgS) in old paintings is a reaction product of HgS with chloride. The chloride narrows the band gap and, as a result, light-induced electrochemical processes can take place: Hg(II) is reduced to Hg(o) as nanospheres of metallic mercury (optical black) and the sulphide oxidizes to SO_2, which vaporizes. Subsequently, chlorides react with metallic mercury to form various white mercury chlorides. This insight was a significant step in understanding the ageing processes in paintings. In 2007, the Royal Netherlands Academy of Arts and Sciences (KNAW) awarded Jaap Boon with the Gilles Holst Medal for his research.

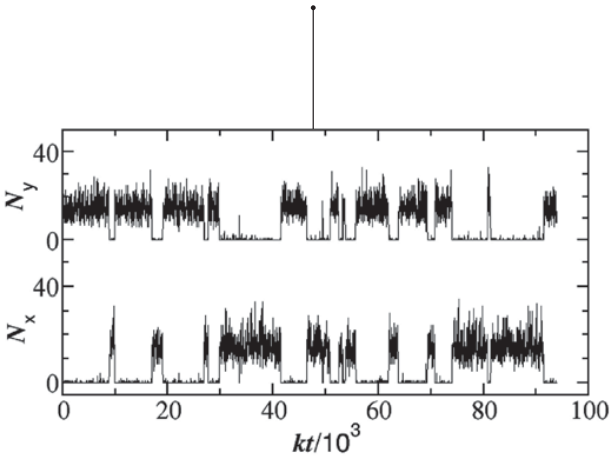
AMOLF starts group at Philips

In 2005, AMOLF began a new research group on the Philips research campus in Eindhoven. Under the leadership of Jaime Gómez Rivas, the group carries out fundamental research into the generation and manipulation of light at the nanoscale. This knowledge is relevant for applications in various areas, including lighting and biosensors. Knowledge transfer between AMOLF and Philips (in both directions) increased considerably as a result of this cooperation. The contract between FOM and Philips was extended in 2010.

Rare but important events simulated

R. J. Allen, P. B. Warren and P. R. ten Wolde, Phys. Rev. Lett. 94, 018104 (2005).

Traffic-jams, financial crashes, crystal nucleation, protein folding, polymer translocation, flipping of genetic switches are all examples of rare events – phenomena that do not occur very often but, if they do, they have considerable consequences. There is now an algorithm which enables us to efficiently simulate this type of unusual events in equilibrium and out-of-equilibrium systems.

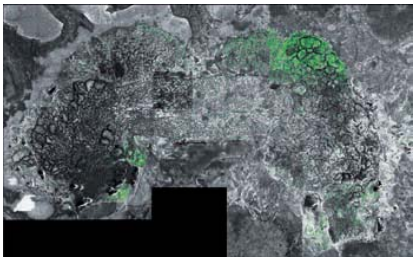


Nanophotonics inspires visual artist

Kobus Kuipers's work inspired visual artist Voebe de Gruyter to design a monument for the victims of chemical weapons on the occasion of the tenth anniversary of the Organisation for Prohibition of Chemical Weapons (OPCW) in The Hague.
The monument was unveiled by Queen Beatrix in May 2007.

2006

Localization of neuropeptides in brain tissue



A.F.M. Altelaar, J. van Minnen, C.R. Jiménez, R.M.A. Heeren and S.R. Piersma, Anal. Chem. 77, 735 (2005)

Neuropeptides in the brain regulate biological processes which are essential for life, such as reproduction and eating behaviour. The chemical structure of neuropeptides and their location jointly determine which processes are switched on or off. High-resolution imaging mass spectrometry was used to determine which neuropeptides are active in which neuronal cells during certain stages of life of the fresh water snail Lymnea stagnalis.

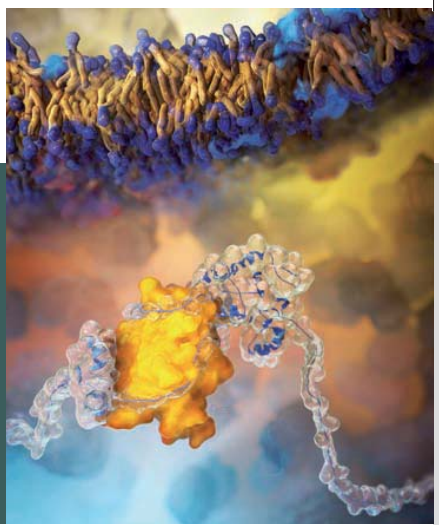
Entropy as 'motor' in living cells

S. Jun and B.M. Mulder, Proc. Natl. Acad. Sci. USA 103, 12388 (2006).

It is still a puzzle how bacteria divide their copied chromosomes in an ordered fashion during cell division. Computer simulations showed that long polymers spontaneously separate into small cell-shaped volumes and distribute themselves between the cell halves. The driving force behind this division of chromosomes is provided by entropy: the 'disorder' to which all molecules strive.

The National Think Tank

In 2004, a group of AMOLF doctoral students and postdoctoral researchers participated in an essay competition organized by the foundation 'The Evening of Science and Society (Stichting de Avond voor Wetenschap en Maatschappij)'. They won the second prize with their idea for setting up 'The National Think Tank'. The idea of this think tank is for a group of young scientists to find solutions to societal problems by combining the expertise of the scientific and business communities and government organizations. The Think Tank chooses an annual topic which is worked on for three months by a group of about 20 doctoral students and postdoctoral researchers selected on the basis of strict criteria. AMOLF has had a representative in the Think Tank every year since its inception.



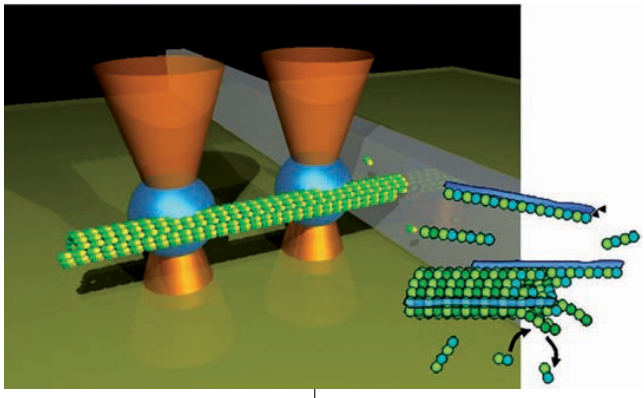
© Sander Tans, Graham Johnson

The influence of chaperones on protein folding observed for the first time

P. Bechtluft, R. van Leeuwen, M. Tyreman, D. Tomkiewicz, N. Nouwen, H. Tepper, A. Driessen, and S.J. Tans, Science 318, 1458 (2007).

Knowledge of the way in which proteins fold is of direct importance for the understanding of various brain disorders, but how this process is accompanied by chaperones is difficult to investigate. This study showed that this can be realized by looking at a single folding protein with optical tweezers. Surprisingly enough, the chaperone only affects a specific folding phase.

2006



Dynamics of microtubules measured with molecular resolution

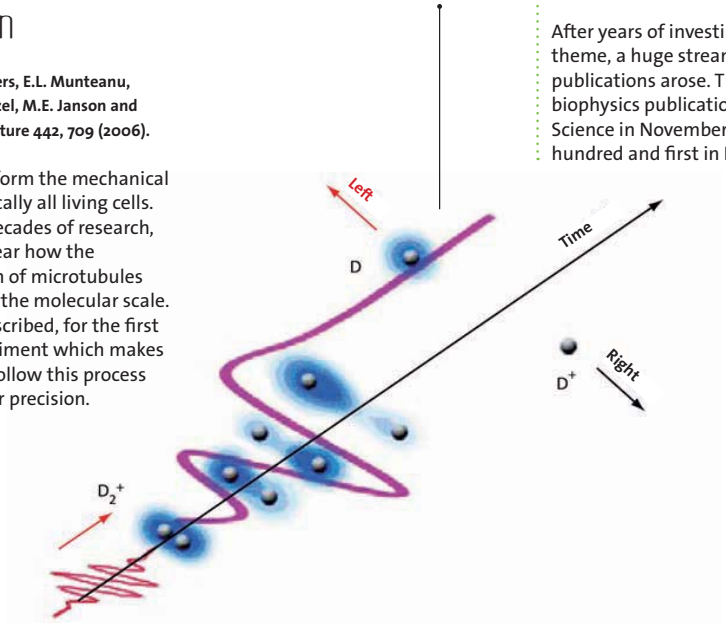
J.W.J. Kerssemakers, E.L. Munteanu, L. Laan, T.L. Noetzel, M.E. Janson and M. Dogterom, Nature 442, 709 (2006).

Microtubules form the mechanical basis of practically all living cells. Despite two decades of research, it is still not clear how the polymerization of microtubules takes place on the molecular scale. This article described, for the first time, an experiment which makes it possible to follow this process with molecular precision.

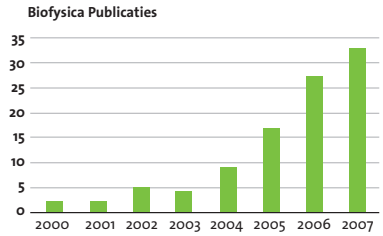
Controlled localization of electrons in molecular dissociation

M.F. Kling, C. Siedschlag, A.J. Verhoef, J.I. Khan, M. Schultze, T. Uphues, Y. Ni, M. Uiberacker, M. Drescher, F. Krausz and M.J.J. Vrakking, Science 312, 246 (2006).

In the first example of control over the movements of electrons on a time scale of attoseconds, a phase-stabilized laser was used to selectively localize the electron in an H_2^+ molecule on one proton, or the other.



2007



100th biophysics publication

P. Bechtluft, R. van Leeuwen, M. Tyreman, D. Tomkiewicz, N. Nouwen, H. Tepper, A. Driessen and S.J. Tans, Science 318, 1458 (2007).

J.W.J. Kerssemakers, E.L. Munteanu, L. Laan, T.L. Noetzel, M.E. Janson and M. Dogterom, Nature 442, 709 (2006).

After years of investing in this new theme, a huge stream of biophysics publications arose. The hundredth biophysics publication appeared in Science in November 2007 and the hundred and first in Nature.

IN THE NEWS

Nano Valley on the Amstel

Parool, October 18, 2008
The Dutch daily newspaper Parool features an article on the Netherlands' position in nanotechnology and interviews Albert Polman.
Good news: The Netherlands excels in the field of nanotechnology, a market which will soon be good for large turnover figures. Amsterdam may even become the Nanovalley of Europe, experts say.


40 economie

Nano Valley
aan de Amstel

Goed nieuws: Nederland excelleert op het gebied van de nanotechnologie, een markt die al snel goed zal zijn voor hallucinante omzetcijfers. Amsterdam kan zelfs uitgroeien tot het Nano Valley van Europa, zeggen deskundigen.

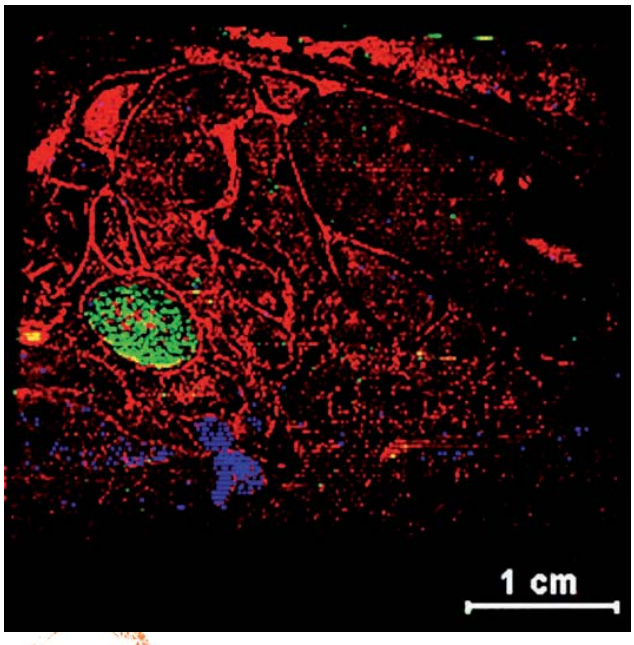
economie 41

Industrie van de toekomst rekent al met miljarden

2008

Imaging MS facility used by pharmaceutical industry

The molecular imaging facility at AMOLF was used, in cooperation with various pharmaceutical companies, to investigate the metabolism of medicines.
The high resolution label-free technology developed at AMOLF showed which cells and organs play an active role in metabolism. This increased understanding of the specific action of medicines.

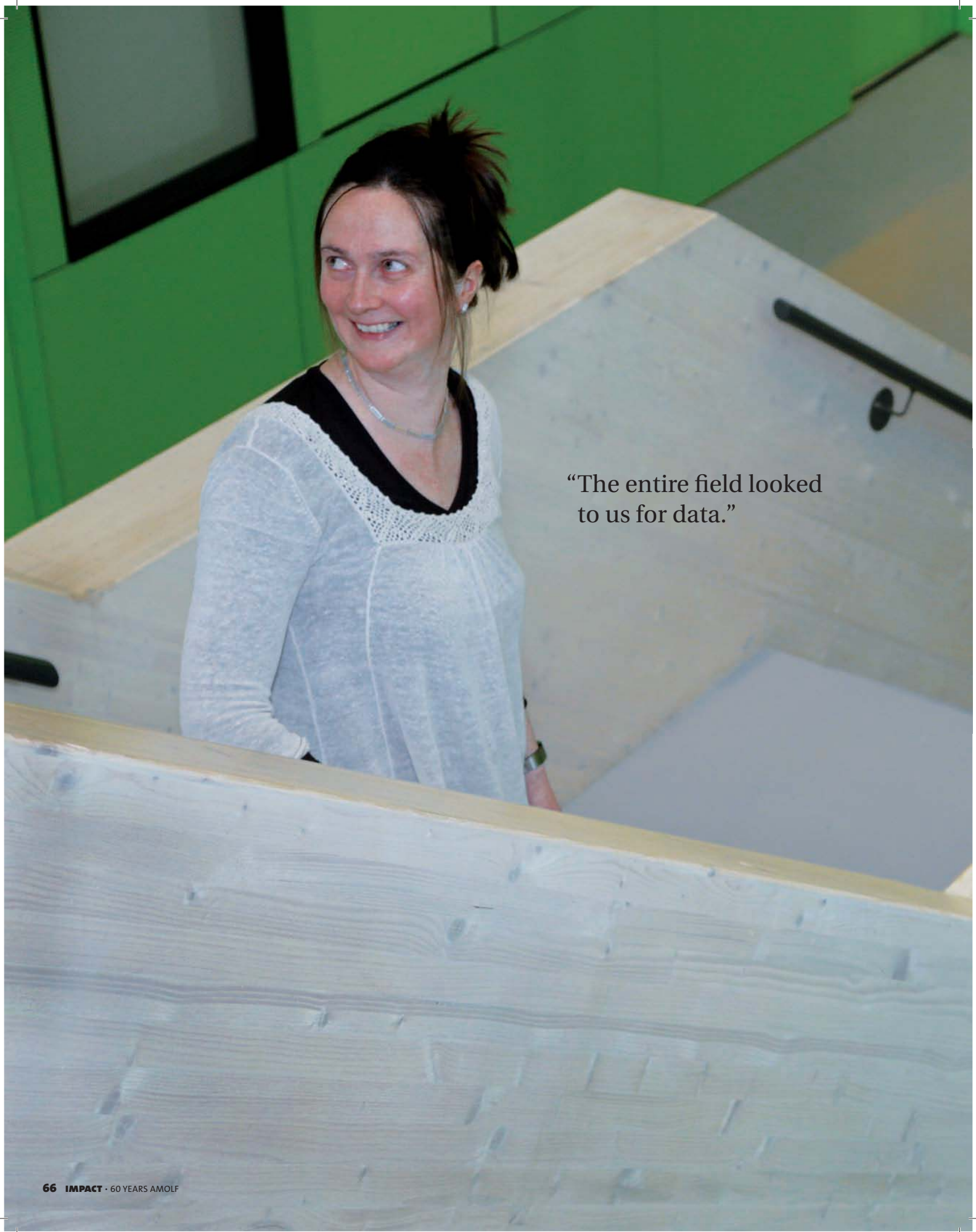


2009

New application for detectors used for high-energy physics

G. Gademann, Y. Huismans, A. Gijsbertsen, J. Jungmann, J. Visschers and M.J.J. Vrakking, Rev. Scient. Instr. 80, 103105 (2009) .

In cooperation with researchers from Nikhef, Medipix detectors, originally developed as x-ray detectors, were used for spatially resolved detection of electrons and ions. This led to interesting applications in chemical physics and biomolecular mass spectrometry.



"The entire field looked to us for data."

MARILEEN DOGTEROM

“I asked myself: HOW EXACTLY DO MICROTUBULES GROW?”

Marileen Dogterom began as a group leader at AMOLF in 1997 and has been head of the department of Biomolecular Physics and a member of the management team since 2003.

“The rigidity of cells is determined by the mechanical properties and dynamics of structures known as ‘microtubules’. Microtubules are thin, stiff protein tubes with a cross section of 25 nanometres and a variable length of up to many micrometres. The fact that microtubules continually change in length is due to the fact that they can switch arbitrarily between periods of growth and shrinkage. We know, furthermore, that they exert a force on other structures in the cell by growing. Microtubules are, for example, very important in pushing chromosomes into place and ‘carrying them away’ during cell division. By growing, they literally give a chromosome a push in the right direction.

In order to understand how a microtubule exerts force, and how much, you first have to understand how the growth process works. We know from biological measurements that the tubular shape of microtubules consists of thirteen ‘chains’ of protein molecules. With ordinary light microscopy it is possible to show a single growing microtubule and measure its speed of growth, but this method does not provide enough resolution to see the growth protein by protein. And that is what we want to do. Using various equipment, including optical tweezers, we developed a set-up with which we could have a microtubule grow in a specific direction. We were able to follow this growth on the nanometre scale. We still could not see exactly what was happening at the protein level, but we did get substantially closer. Furthermore, we were the first in the world to achieve this. The entire field, including our competitors, was looking to us for data. We are still a long way from agreeing on the interpretation as it was a completely new type of data and the analysis was very complex.

We had this experiment in the back of our mind for years and it was fantastic that it had now all come together and worked. The biochemical aspects, in particular, were terribly complicated. You cannot, moreover, keep carrying out this kind of experiment forever. It simply does not work very often. I know for certain that we will be able to measure with a still higher resolution in the future, and that we will then actually be able to answer the question of how microtubules grow. But first we want to understand what we have already seen. Although the experiments are only a model of how the process could go in a living cell, our motivations are biological. There is so much in the cell that we do not understand.

If we can map the growth process of microtubules in cells at the nanoscale, we will have a better understanding of the processes in a living cell and ultimately know why certain processes go wrong in a sick cell.” •

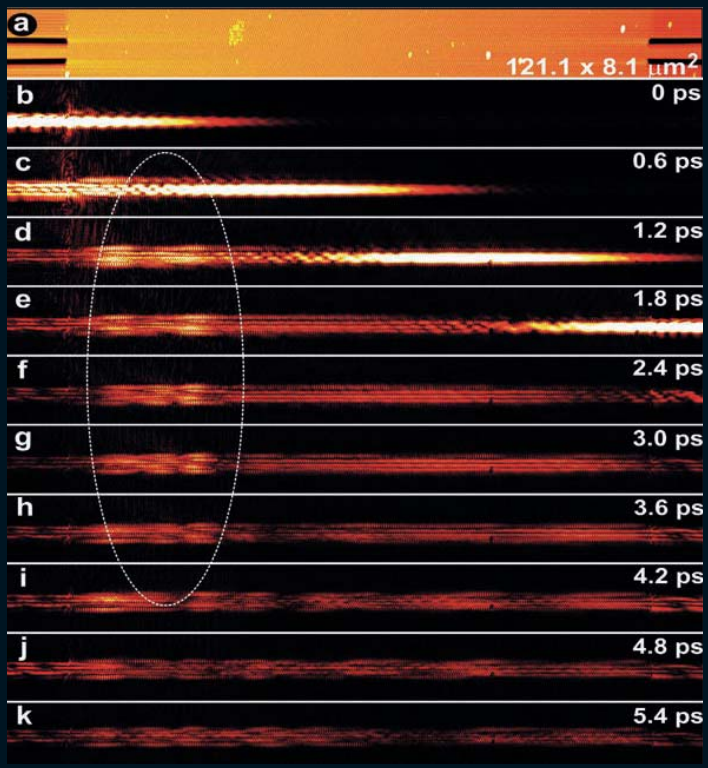
WHERE DO AMOLF RESEARCHERS CURRENTLY COME FROM?

AMOLF AS AN INTERNATIONAL LABORATORY

EXTREME

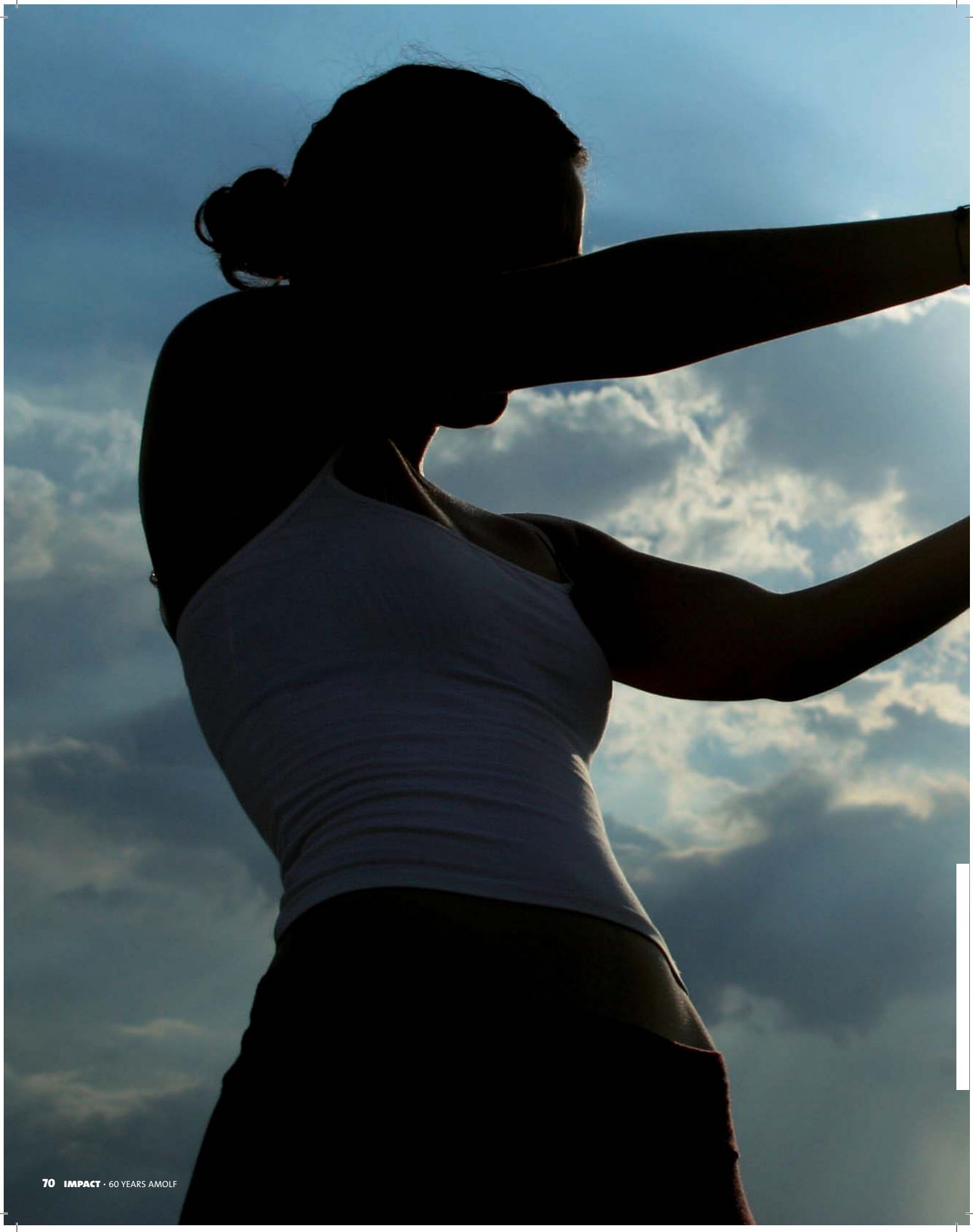
THE SLOWEST LIGHT

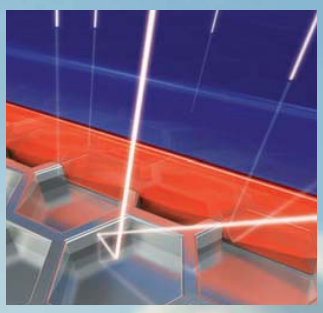
SLOWING DOWN LIGHT IN A PHOTONIC CRYSTAL



H. Gersen, T. J. Karle, R. J. P. Engelen, W. Bogaerts, J. P. Korterik, N. F. van Hulst, T. F. Krauss and L. Kuipers, Phys. Rev. Lett. 94, 073903 (2005).

The periodic pattern of hones in a photonic crystal has a large influence on the behaviour of light in the crystal. Some colours are forbidden in the crystal, while others do propagate, be it very slowly. The illustrations show snapshots of a light pulse penetrating a photonic crystal from the left and subsequently slowing down to a speed less than 1/1000 of the speed of light.





Plasmonic solar cell: metal nanostructures are used to capture light in a solar cell.

2010...future

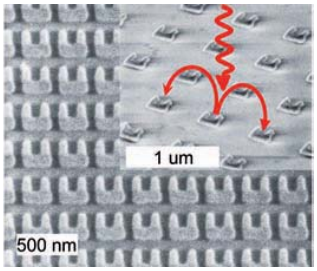
THE FUTURE

Further understanding and control of the world around us is our greatest challenge for the future. The research carried out in recent decades has partially satisfied our curiosity regarding the building blocks of the world around us and the origin of our own existence. It has also become clear that our current society is built on technology that has been developed by decades of investment in fundamental research. It is vital that we continue to invest in this research in the future if we are to answer important questions relating to science and society. The challenges facing today's AMOLF research leaders are listed in this last chapter.

FEMIUS KOENDERINK

My challenge for the future:

"Nano-wifi antennas, so that a few molecules communicate via a couple of light quanta; for us, every photon is precious."



Light's magnetic field drives nano-LC resonances

I. Sersic, M. Frimmer, E. Verhagen and A. F. Koenderink, Phys. Rev. Lett. 103, 21903 (2009).

Normal materials only interact with light's electric field. This experiment showed for the first time that U-shaped nanorings made of gold interact directly with light's magnetic field. The rings act as small current coils with a single winding. They show a very strong magnetic response at optical frequencies due to an LC resonance that can be used for new optical materials.

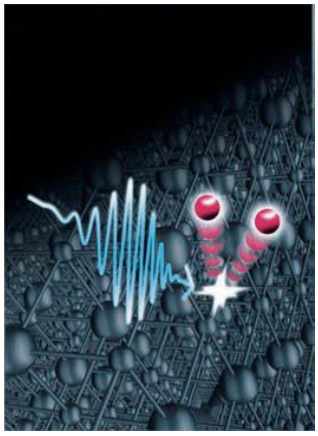
MISCHA BONN

"The real challenge is to find patterns within complex systems such as solar cells and cell membranes."

Photovoltaic magic of quantum dots unmasked

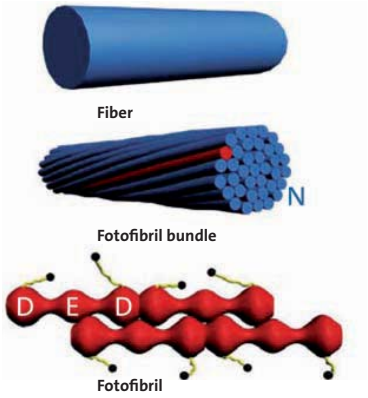
J. J. H. Pijpers, R. Ulbricht, K.J. Tielrooij, A. Osherov, Y. Golan, C. Delerue, G. Allan and M. Bonn, Nature Phys. 5, 811 (2009).

A significant limitation of current solar cells is that only a single electron is generated for each light particle (photon) absorbed. It was always assumed that more electrons could be generated per photon in semiconductor nanocrystals (quantum dots) than in bulk material. Recently it became apparent that this process is more efficient in bulk material than in quantum dots. This was a significant discovery for the further development of solar cells.



GIJSJE KOENDERINK

"I would like to know how we can make smarter and stronger materials, with the living cell as source of inspiration."



Supramolecular architecture of fibrin is essential for the clotting of blood

I. Piechocka, M. Bacabac, M. Potters, F.C. MacKintosh and G.H. Koenderink, Biophys. Journ. 98, 2281 (2010).

If we hurt ourselves, our blood immediately begins to clot. This localized response is due to the polymerization of fibrin to form an elastic network. Using rheology, AMOLF researchers showed that fibrin networks tolerate extremely large forces because the fibrin threads have a hierarchical structure which absorbs distortion by deforming reversibly on different length scales. This provides insight into the causes of coagulation diseases and in design principles for new materials.

JAAP BOON

KOBUS KUIPERS

AMOLF BEYOND 2010

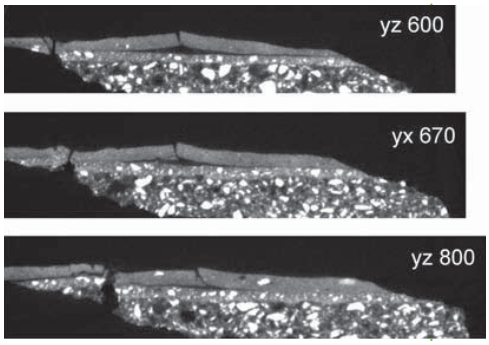
AMOLF has acquired a very strong position in its two principal themes: biophysics and nanophotonics. The institute has built up an ultramodern infrastructure for this research and will now be able to harvest the benefits.

"What I would like to do is to expand the 3D X-ray research of submicron structures in composite material on my own."

3D Examination of 'The Art of Painting' by Johannes Vermeer

J.J. Boon and E. Oberthaler, in: Vermeer Die Malkunst - Spurensicherung an einem Meisterwerk, exhibition catalogue, Vienna, January 2010.

For his white tile floor, Johannes Vermeer used a unique and highly-refined oil paint with lead-white nanocrystals, which are now flaking off because the original oil medium has become a crystalline halatopolymer. By means of successive virtual cross sections, x-ray tomographic microscopy in the SLS synchrotron at PSI, Switzerland, provided an image of a shell-shaped contraction crack which forms the start of the delamination process of the glass-hard paint surface.

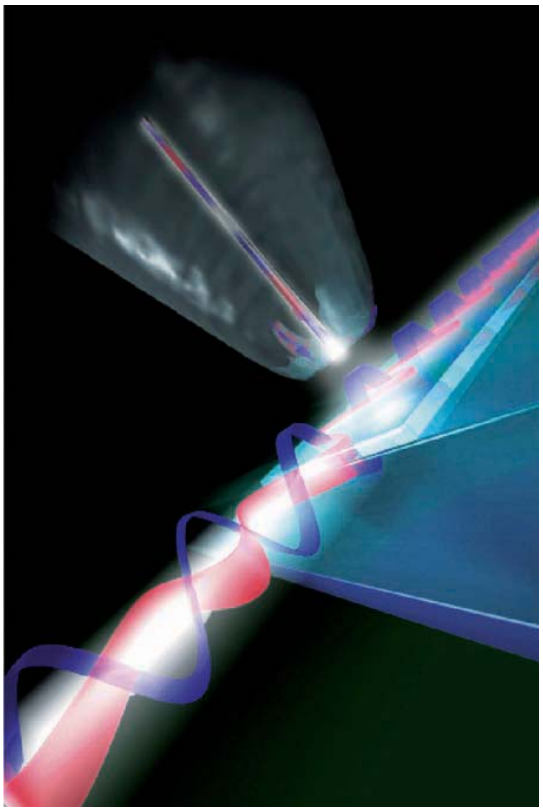


"I think it would be fantastic to be able to capture light and release it again a little while later."

Measuring light's magnetic field

M. Burresi, D. van Oosten, T. Kampfrath, H. Schoenmaker, R. Heideman, A. Leinse and L. Kuipers, Science 326, 550 (2009).

Light is an electromagnetic wave composed of oscillating electric and magnetic fields which are inseparably linked to one another. The magnetic field plays a negligible role in the interaction between light and matter at optical frequencies. If we see light, we 'see' the electric field but are blind to the magnetic field. With a smart nanoprobe, however, it is possible to observe the magnetic field phase-sensitively with sub-wavelength spatial resolution. This is important if we are to develop greater understanding of light at the nanoscale.



JAIME GÓMEZ RIVAS

SANDER TANS

ALBERT POLMAN

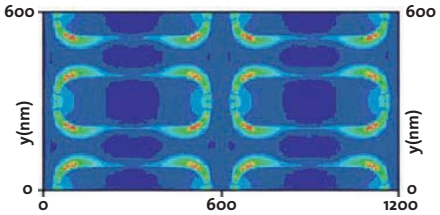
My challenge for the future:

"Forcing light into a volume a million times smaller than the wavelength."

Resonante plasmon antenne arrays

G. Vecchi, V. Giannini and J. Gómez Rivas, Phys Rev. Lett. 102, 146807 (2009).

Gold nanoparticles can now be manufactured very accurately using sophisticated nanofabrication techniques. The interaction of light with these particles is comparable with the interaction of radio waves with antennas; they have therefore been dubbed 'nantennas' or 'nanoantennas'. If nanoantennas are installed neatly on a grid, they reinforce one another's antenna action. This collective action leads to very sharp resonances in the spectrum of the antenna grid. These resonances can be used to improve the efficiency of sensors.



"I want to show how a chaperone folds up a protein."

Bacteria switch on expression of a single gene

A.M. Adiciptaningrum, I.C. Blomfield and S.J. Tans, EMBO reports 10, 527 (2009).

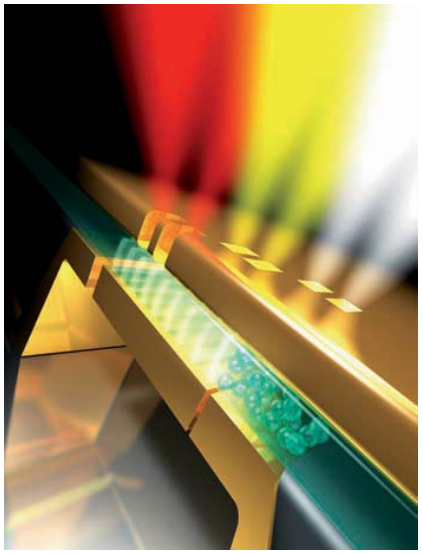
Growing bacteria have multiple copies of their chromosome and, therefore, also of all their genes. Can a single copy be switched on? The use of green fluorescent proteins and a detailed analysis of a few cells showed that the fim gene can do just this by means of a special regulating mechanism based on DNA recombination. This process plays a direct role in bacterial infections.

"I want to cause a revolution in solar cell technology using nanophotonics."

Electrically excited surface plasmons

R.J. Walters, R.J.A. van Loon, I. Brunets, J. Schmitz and A. Polman, Nature Materials 9, 21 (2010).

Plasmons are electromagnetic waves which propagate on the surface of a metal. They are so small that they fit in a computer chip and, consequently, unite optical communication and electronic chip technology. We succeeded in electrically exciting plasmons in a sandwich of two thin gold films with a layer of alumina with Si nanocrystals in between.

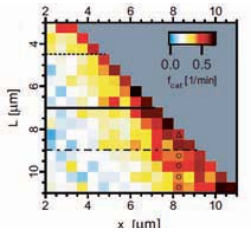


MARILEEN DOGTEROM

PIETER REIN TEN WOLDE

"How mechanical forces organize the inside of a cell is what I would like to be able to understand."

Force organizes dynamics of microtubules in living cells



C. Tischer, D. Brunner and M. Dogterom, Mol. Sys. Biol. 5, 250 (2009)

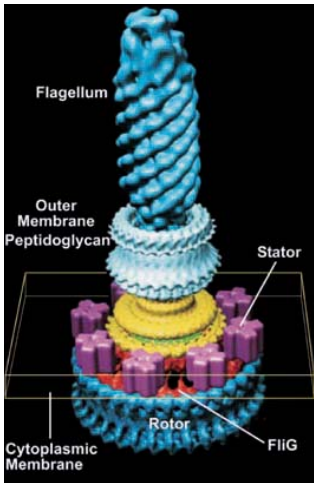
We have known for some time, from experiments in purified systems, that microtubules can exert pushing forces and that, as a result, their growth dynamics change. This article showed for the first time that the dynamics in living yeast cells also change as soon as forces are applied. This enables the cell to adapt the dynamics of microtubules specifically when they reach the end of the cell.

"I would like to understand how living cells code information in the spatio-temporal dynamics of biomolecules, such as proteins and DNA."

Molecular motors can change gear through mechanical feedback

S.B. van Albada, S. Tanase-Nicola and P.R. ten Wolde, Mol. Sys. Biol. 5, 316 (2009).

Many species of bacteria are propelled by structures known as flagella which are driven by molecular motors. Not only do these motors change gear in response to biochemical signals but also to mechanical feedback: if the force on the motor becomes too large, the motor is more likely to change to another gear.



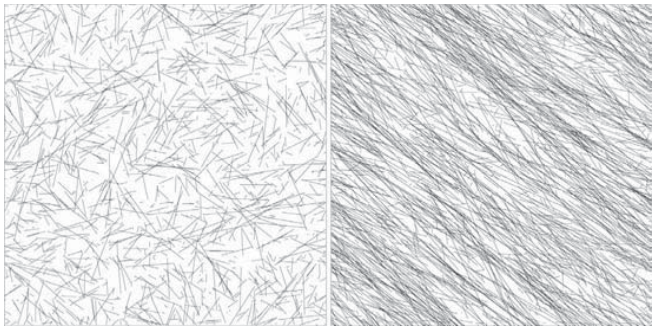
High-quality technical support

For sixty years, AMOLF's researchers have been able to count on expert technical support. The design department, mechanical workshop and electronics and software departments have always played an essential role in the institute's research. AMOLF will continue to invest in the best equipment and facilities for these departments so that they will also be ready for the institute's future research programme.

F.l.t.r. Wim Brouwer (Head Mechanical Workshop), Marco Konijnenburg (Head Software Engineering), Iliya Cerjak (Head Design Department), Carl Schulz (Head ICT) and Duncan Verheijde (Head Electronics Engineering)

BELA MULDER

My challenge for the future: *" Closing the gap between molecule and cell with exciting theory is a dream to work towards."*



Colliding microtubules line up in the cortex of plant cells

S. Tindemans, R. Hawkins and B.M. Mulder, Phys. Rev. Lett. 104, 058103 (2010).

The cortical network of neatly aligned microtubules which is characteristic of and functionally important for growing plant cells appears to arise by self organization. Using a combination of an analytical model and simulations of colliding dynamic microtubules in a two-dimensional plane, we see that the organization arises as a result of a selection mechanism which does not allow misaligned microtubules to live as long.

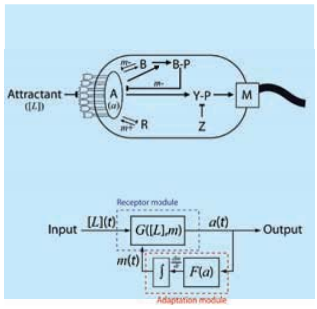
TOM SHIMIZU

"My target is to connect the design of molecular signal networks in living cells to the restrictions imposed by their behaviour and evolution."

Biomolecular information networks

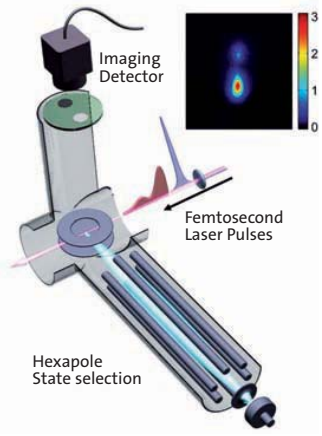
T. S. Shimizu, Y. Tu and H. C. Berg, Mol. Sys. Biol., 6:382 (2010).

We are looking for a physical understanding of networks which process information in living cells by means of in-vivo measurements of essential molecular interactions and coarse-grain models. The latter may describe the essential physics and may allow an analytical approach to biologically relevant functional properties.



MARC VRAKKING

"My challenge is to film what electrons do during a chemical reaction."



Orientation and alignment of quantum-state selected NO molecules

O. Ghafur, A. Rouzée, A. Gijsbertsen, W.-K. Siu, S. Stolte and M.J.J. Vrakking, Nature Physics 5 289 (2009).

The development of new x-ray-free electron lasers has cleared the way for following changes in molecular structures during chemical or biochemical reactions using x-ray diffraction. All molecules must, however, be oriented in the same direction at the beginning of the experiment for the reaction to take place. This is realized by a combination of laser and continuous electric fields.

AD LAGENDIJK

RON HEEREN

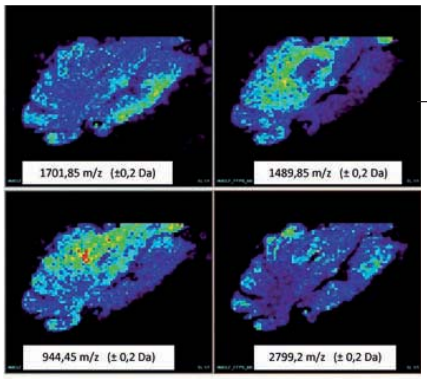
HUIB BAKKER

"I would now finally like to know how scattering takes place."

Variation of the effective refractive index to measure optical transport in chaotic media

S. Faez, P.M. Johnson and A. Lagendijk, Phys. Rev. Lett. 103, 053903 (2009).

Filling porous media with a gas under varying pressure can dramatically influence the transport of light along long paths. Changes in the refractive index of as little as 10^{-4} are sufficient to bring about changes. This simple new method can be used to determine the most important transport parameters of light and can be used for many materials.



"I want to understand how cells in tissue pass on chemical signals by determining where what protein is located in and under a cell surface. We are on a biochemical voyage of discovery on a cubic micrometre."

Revealing the conformation of proteins in tissue using gas phase mobility measurements

J. Stauber, L. MacAleese, J. Franck, M. Snell, E. Claude, B. Kükrer Kaletas, I. van der Wiel, M. Wisztorski, I. Fournier and R.M.A. Heeren, J. Am. Soc. Mass Spec. 21, 3:338 (2010).

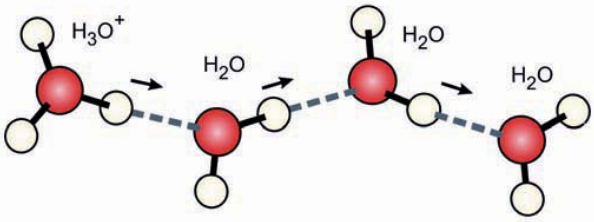
The function of proteins is determined by their composition of amino acids and their shape. With the aid of ion mobility spectrometry (identification based on collision cross section), proteins of an identical nominal molecular weight were distinguished on the basis of their shape. Combined with imaging mass spectrometry, this led to the visualization of new structures in tissue cross sections of neurological material which would have remained hidden without this differentiation by shape.

"If we really understand how water works, a great deal will become clear."

How water conducts protons

K.J. Tielrooij, R.L.A. Timmer, H.J. Bakker and M. Bonn Phys. Rev. lett. 102, 19 (2009) .

How protons are conducted through water was examined using THz pulses with a duration of a picosecond. The measurements showed that the proton is strongly linked to four water molecules: it forms an $H_9O_4^+$ structure. It appears that no less than fifteen surrounding water molecules have to rearrange themselves to pass on the proton charge to other water molecules.



"The manipulation and 'teasing' of light became an objective in itself."

KOBUS KUIPERS

“I asked myself: HOW CAN I BRING LIGHT TO A STOP”

Kobus Kuipers began at AMOLF as a masters student in 1988 and carried out PhD research there from 1990 to 1994. In 2003, he came back to the institute as a group leader. He also leads AMOLF’s Centre for Nanophotonics and is a member of the management team since 2006.

“Light has fascinated me my whole life, but there was, in the first instance, a practical reason for the fact that light at the nanoscale actually became a research topic. I studied individual molecules at the beginning of my career. That required all sorts of tricks involving the manipulation of light at the smallest possible scale. That was so complicated that the manipulation and ‘teasing’ of light became an objective in itself.

Light moves with incredible speed and is difficult to catch. This is due to the nature of the materials around us, as well as the characteristics of light. But it is precisely because it is such an elusive phenomenon that it is so exciting. It would be a real achievement to actually manage to capture light and bring it to a stop. Of course, this idea did not simply come out of the blue.

Our understanding of the manipulation of light in photonic crystals, in particular, gave us the idea that we might be able to stop light in its tracks.

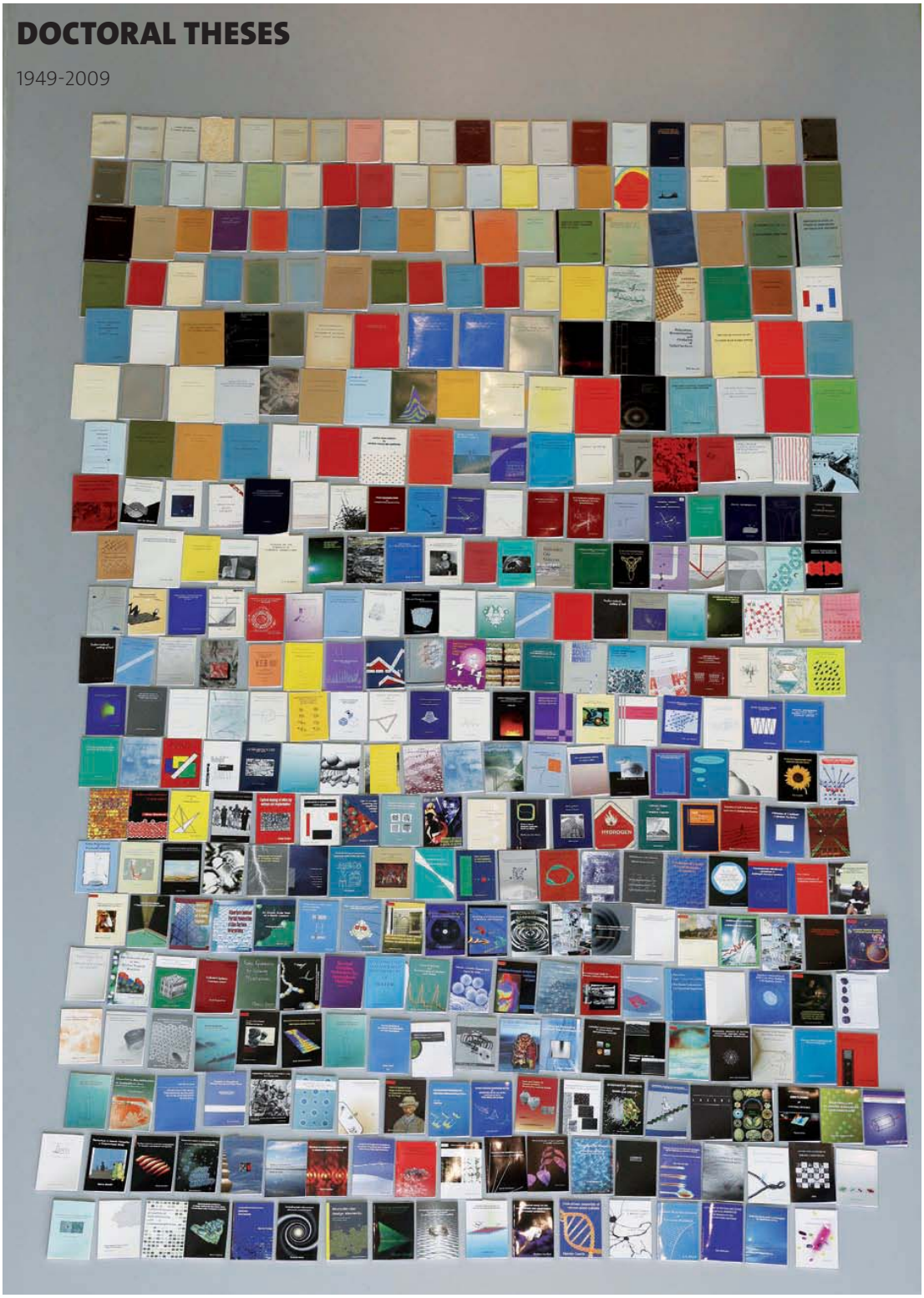
In a photonic crystal, materials are stacked, at the nanoscale in such a way that certain colours of light cannot exist in it. Suppose that you make a cavity inside a crystal of this kind, where light can exist. If you succeed in getting the light into that cavity, you have caught it. To this end, you would have to manipulate the crystal such that you temporarily open a door, as it were, and once the light is inside, close it again quickly.

Just because you have trapped it, does not mean that the light has been brought to a standstill. To achieve this we have to go a step further. It appears that when we manipulate a photonic crystal very close to the point at which light is excluded, light becomes very slow. This gives you extra switching time. If I first slow down the light and subsequently change the crystal so that the light is excluded, I can, theoretically, freeze it.

In practice this is still extremely tricky, one of the reasons being that the colour of light itself can change if you actively change something about the crystal. We do not, as yet, have the solution, but ‘the journey’ is wonderful. We have run into some fascinating physics on the way. For example, the discovery that slower light is more sensitive to faults in the crystal was, at first, a disappointment because it made our experiments more complex. At the same time, however, it provided all sorts of new fundamental insights into light.
This research is an exciting challenge but there is more to it than that. If the work is successful, we will be able to use it for a lot of practical purposes. This is why, in this fundamental research, we use wavelengths that are relevant for applications. The near-infrared spectrum, for instance, is used a lot in telecommunications.” •

DOCTORAL THESES

1949-2009



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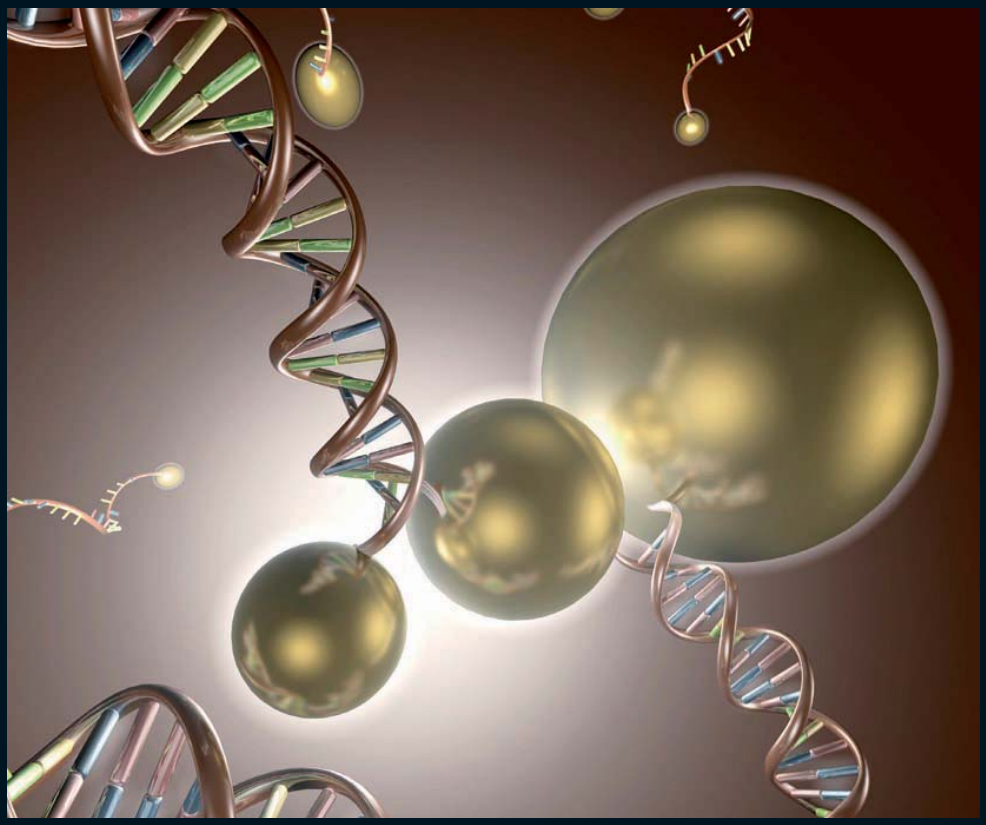
TOTAL 392 DOCTORAL THESES

EXTREME

THE SMALLEST OBJECT
A PLASMONIC NANOLENS



S. Bidault, F.J. García de Abajo and A. Polman, J. Amer. Chem. Soc. 130, 2750 (2008).

Three gold spheres with a diameter of 5, 10 and 20 nm respectively were threaded onto one another to form a structure in which light could be concentrated into a volume of only a few nanometres. The structure was made with a DNA template technique, in which the individual gold spheres are selectively bound to preprogrammed base pairs of DNA.

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