STRINGS, MIRRORS AND TAPE

70 years of Dutch physics

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FOM

CONTENTS

Strings, mirrors and **tape** are part and parcel of physics, from rarefied mathematical physics to prosaic experimental ingenuity.

Strings are mini-elastic bands that can vibrate in many different ways and that replace elementary particles, such as electrons or quarks, in string theory (an extreme form of theoretical physics that works with additional dimensions).

Mirrors, reflecting or semi-translucent, are an essential component of numerous physics experiments ranging from quantum teleportation to demonstrating the existence of gravitational waves.

Tape seals leaks and holds experimental setups together. The Scotch tape method is used to produce graphene by peeling off thin layers of graphite (pencil lead) with a piece of adhesive tape.

Page 2: BOL experiment Nikhef

Page 4: Researcher Anne Meeussen (AMOLF) busy with scissors and foil

Foreword

FOM is dead; long live FOM!

In 2012 Leo Kouwenhoven's Group at Delft University of Technology was the first to detect the long-sought Majorana particle. Three years later, fellow physicists led by Ronald Hanson demonstrated the existence of 'spooky action at a distance' in the quantum world – an experiment that proved Einstein wrong and made front-page news in *the New York Times*. Two examples of top physics in the Netherlands realised with funding from FOM, the Foundation for Fundamental Research on Matter.

Dutch physics is doing well. That is due to the high quality. This concerns both research inspired by the desire to understand nature at a fundamental level as equally research intended to help society advance. The exceptional position of Dutch physics is apparent from the feedback and reviews from foreign colleagues, from an article in *Nature* about the exceptionally high impact of Dutch publications and, of course, superb results. When the Dutch *de Volkskrant* newspaper listed the ten most influential scientists in the Netherlands, eight of these were physicists.

This Dutch top physics research takes place at universities, institutes and the laboratories of multinationals like Philips and Shell. FOM occupies a unique position in this system. Since 1946 FOM has actively supported high-quality research that makes a difference. FOM started as a small organisation that mainly served nuclear physics and over the course of its 70-year existence it has grown into a significant actor with a budget of 108 million euros and 1100 employees in 2015. In that year these employees produced 105 PhD theses and 1187 publications in renowned scientific journals. There is much more physics in the Netherlands but FOM is without doubt the driving force and trendsetter.

As part of the transition of the Netherlands Organisation for Scientific Research (NWO) FOM will become part of the new NWO on 1 January 2017 and will then cease to exist as an independent organisation. So now is a highly appropriate moment to provide a brief history of this striking, unconventional and influential institute – 'a whale in the pond'.

Dirk van Delft interviewed several key people for the FOM office. For this book he wrote the history of FOM. The editors also made extensive use of the FOM archive, yearbooks and other publications.

See how the water in the canals deforms the reflected facades. As a member of the organising committee of Strings '97, the international conference about string theory, Robbert Dijkgraaf designed a work of art which made it clear at a glance where the string physicists would meet each other: in Amsterdam. Since 2012, Dijkgraaf has been the director of the Institute for Advanced Study in Princeton.

I – Yellowcake, Kjeller and enriched uranium (1945-1955)

The Foundation for Fundamental Research on Matter (FOM) dates back to 15 April 1946. That was the day a learned quartet appeared before H.J. Zweers, civil-law notary in The Hague. The first was Gerard van der Leeuw, Dutch Minister of Education, Arts and Science – and, prior to that, Professor of Religious Studies in Groningen, the Netherlands. The second was

The Dutch delegation of the Atoms for Peace conference in Geneva in 1955

Hans Kramers, Professor of Theoretical Physics in Leiden and a key player in physics in the Netherlands. Kramers was also there on behalf of his physics colleagues, Pim Milatz of Utrecht and Jacob Clay of Amsterdam. The quartet was completed by Henk Reinink, Secretary General at the Ministry (who had a PhD from Groningen in a monetary subject) and Hajo Bruining, secretary to the Prime Minister, Willem Schermerhorn. Bruining had trained as a physicist and had formerly worked at Philips Physics Laboratory (NatLab). The Prime Minister himself was a former professor of surveying at what was then Delft Institute of Technology. A gathering of bright minds which kick-started post-war physics in the Netherlands and gave it a new direction.

Ten days earlier, on 5 April, the name 'Fundamental Research on Matter' had been chosen at a meeting of the Nuclear Physics Commission [*Commissie voor Atoomfysica*]. The original name, 'Foundation for Fundamental Physics Research', encountered objections on that occasion from Gilles Holst, retiring director of NatLab and endowed professor in Leiden. He argued for a 'more inclusive name', one which would not stand in the way of a productive collaboration between physicists and chemists from the very start. It was one of the Commission's members, Jacob Clay, who proposed the broader name of 'Fundamental Research on Matter'.

FOM was therefore the brainchild of the Nuclear Physics Commission, which had been set up by the Dutch government in 1945 and had been given the name 'Advisory Commission on the matter of Nuclear Physics'. Philips became involved due to the cyclotron it had secretly started to build in Eindhoven during the war. The Commission was also occupied with the two hundred barrels of 'yellowcake' with 67 percent uranium content: nuclear fuel that had been acquired by the Dutch government shortly before the outbreak of the war from Union Minière in the Belgian Congo on the advice of Wander de Haas, professor and director of the Kamerlingh Onnes Laboratory in Leiden. The run-up to FOM was thus a lot more than just a catch-up exercise after the war.

Cathedrals of science

The LHC particle accelerator in Geneva, the 1600 detection stations of the Pierre Auger Observatory in Argentina, the High Field Magnet Laboratory in Nijmegen – all three are cathedrals of science. Physicists from throughout the world flock there to conduct experiments. The enormous buildings and vast, high-cost equipment needed in experimental physics make it an expensive discipline. This was one reason for establishing a separate organisation for physics outside of the universities immediately after the Second World War. The founders of FOM, the Foundation for Fundamental Research on Matter, expected to conduct research that was too expensive for individual universities and required a degree of clout not present at the university level at that time.

To achieve something big, cooperation is essential. Physicists work together to develop and operate research facilities: set-ups for creating and studying submicron devices and materials, NMR equipment and, most recently, facilities for nanophysics.

For the very largest projects, international cooperation is inevitable. International research centres were soon created in nuclear and particle physics, and later in nuclear fusion. They were joined by international facilities for neutron sources and synchrotron radiation. Dutch research groups and institutes developed to become the home base of the Netherlands' contribution to large projects of this type. Home-grown particle accelerators were gradually phased out. Dutch physics found other niches where the country could excel internationally, such as free-electron lasers and high magnetic fields.

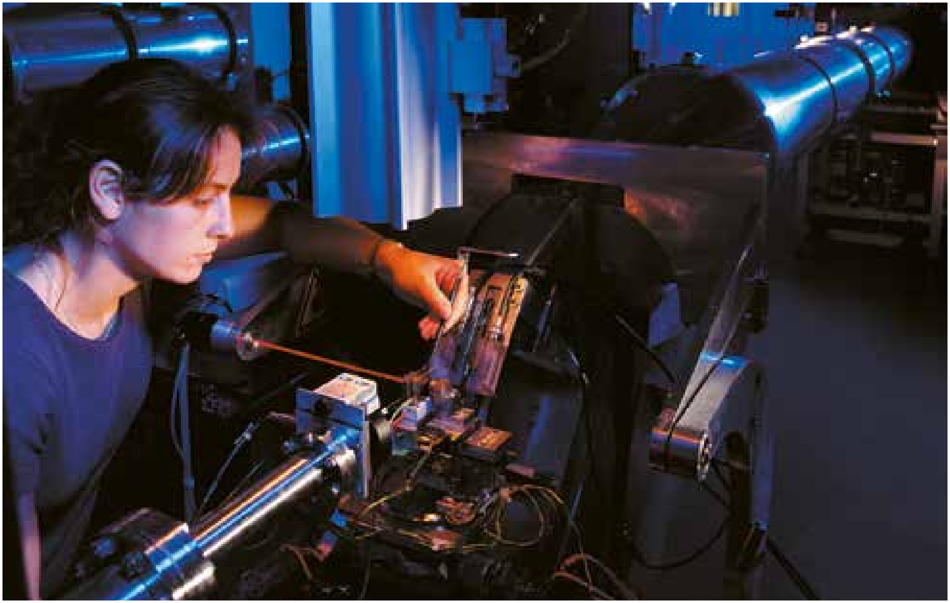
The European Organization for Nuclear Research, CERN, in 1965

Undersea spheres

2006 - At the bottom of the Mediterranean Sea, 2500 metres below the surface, lies the ANTARES neutrino telescope. It consists of twelve vertical cables, each 350 metres long, with a group of three large spheres every 15 metres. The spheres contain photomultiplier tubes with which the telescope observes the seabed. ANTARES measures neutrinos: particles from space that pass through the Earth unimpeded. An occasional undersea collision between a neutrino and an atomic nucleus generates Cherenkov radiation, which ANTARES detects. 150 Physicists and technicians from seven countries, including the Netherlands, worked on the project. In 2016 the neutrino telescope KM3NeT is being constructed as the successor to ANTARES.

Shoulders of giants

The world-famous LHC particle accelerator at CERN, enclosed in an underground pipe 26 kilometres long, is not the only one of its kind. It was preceded by generations of accelerators. One of its predecessors was the HERA accelerator (1992 to 2007) in Hamburg; with a ring six kilometres long, it was no small-scale venture either. The Netherlands was among the countries that worked on the HERA experiments. They were mainly used to unravel the structure of the proton – the nuclear particle contained in all atomic nuclei. By smashing protons in the HERA accelerator and analysing the debris, physicists were finally able to understand how the proton was put together.



Dutch beamline in France

2000 - Physicists needing intense X-rays for their experiments can have their needs met in France. Grenoble is home to the European Synchrotron Radiation Facility (ESRF), a facility that generates radiation a hundred billions times more intense than that used for an X-ray image of a broken arm. The radiation is 'tapped off' into beamlines, 43 in total. Since 2000, the Netherlands and Belgium have had one of these beam lines, DUBBLE, which was built at AMOLF. DUBBLE line X-rays have since shed light on the crystal structure of cocoa butter, on blood clots, solar cells and pigments in paintings.

Dutch-French ion accelerator

1996 - At the KVI, Center for Advanced Radiation Technology, in Groningen, nuclear physicists put the cyclotron known as AGOR (Accélérateur Groningen-ORsay) into service. This compact accelerator equipped with superconducting coils is the largest joint scientific project ever conducted by the Netherlands and France. AGOR accelerates ions of all elements from the periodic table. Researchers use the accelerated ions to study how the structure of atomic nuclei plays a role in supernovae and to investigate the interaction of hadrons, nuclear particles consisting of quarks. They are also working to improve proton therapy, a new type of radiation treatment for cancer. Besides research, the accelerator's uses include testing the radiation hardness of electronics for the aerospace industry.

Inside the core

2010 - Like an insect in its nest; an installation robot crawls through the three-metre-high reaction vessel of the JET fusion reactor in the UK to fit a new wall. The wall protects the vessel against the thin, white-hot plasma that physicists confine inside it. In nuclear fusion, light atomic nuclei fuse together to form heavier ones; this process releases a lot of energy. In France, construction has begun on the ITER fusion reactor, which will be significantly larger than JET. Physicists hope to use ITER to demonstrate the technical feasibility of nuclear fusion as an energy source. Both JET and ITER are international collaborations whose participants include the Netherlands.

Hoger Onderwijs Reactor

1963 - The final phase of construction of the Hoger Onderwijs Reactor (HOR) in Delft. Dutch politician Diederik Samsom would later undertake his thesis project here, designing a meter for very low radiation doses. The HOR does not produce electricity but is instead a research reactor. Physicists in the complex carry out materials research using the neutrons and positrons formed during nuclear fission events in the reactor.

Strings, Mirrors and Sellotape – 70 years of Dutch physics is published to mark the 70th anniversary of the Foundation for Fundamental Research on Matter (FOM). FOM has played a decisive role in Dutch physics since the Second World War. This book contains many images and stories from this period.

FOM covers the entire spectrum of fundamental research, whether the motivation is pure curiosity or the desire to realise applications. FOM is part of the Netherlands Organisation for Scientific Research (NWO). From 2017 onwards it will be integrated within this organisation and in its new role it will continue to support Dutch physics. FOM has a charitable status.

The texts published in this book fall under the responsibility of the authors and do not necessarily reflect the viewpoint of the FOM board and directors.

We would like to thank everybody who has made the realisation of this book possible!

Publication
WBOOKS, Zwolle
www.wbooks.com
in collaboration with
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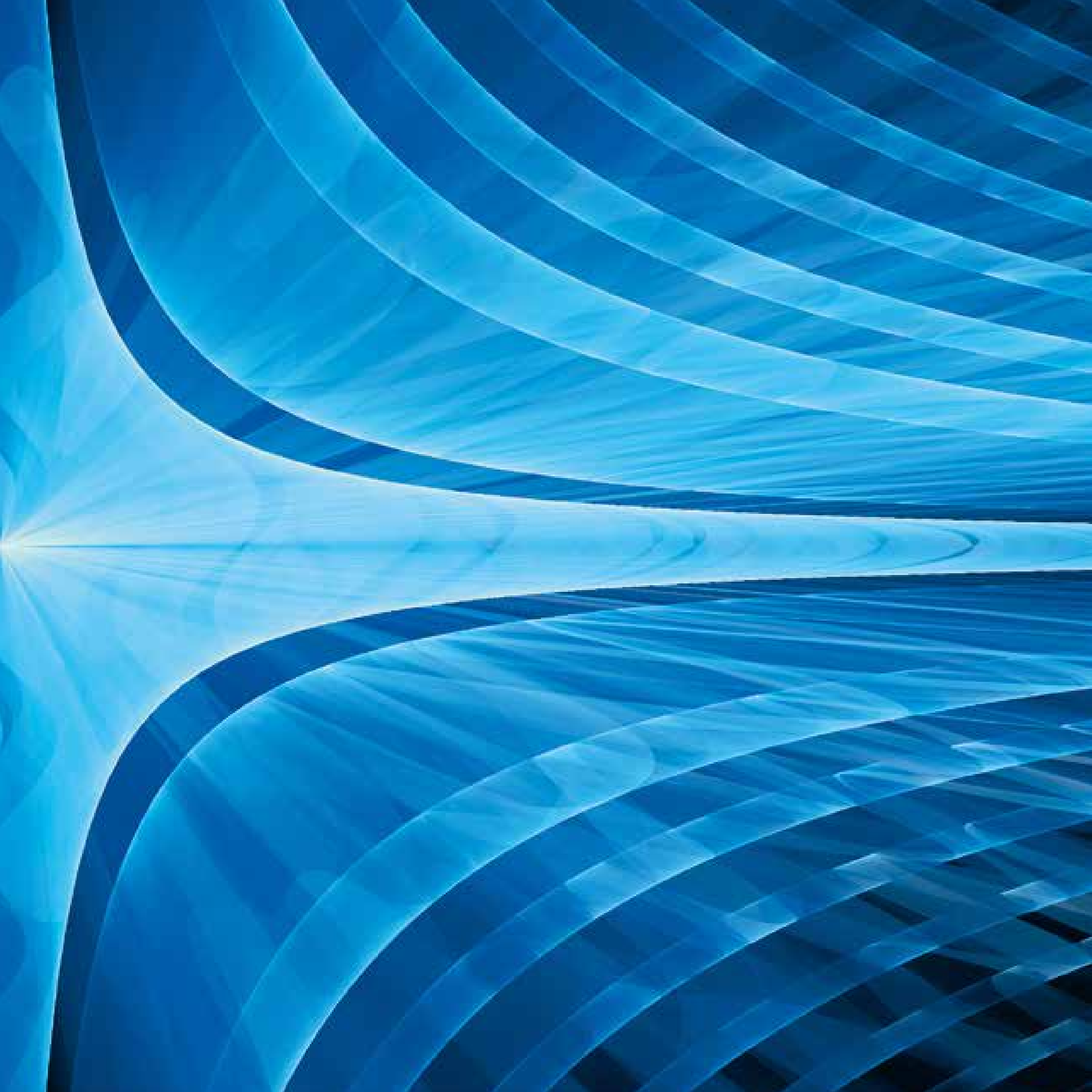
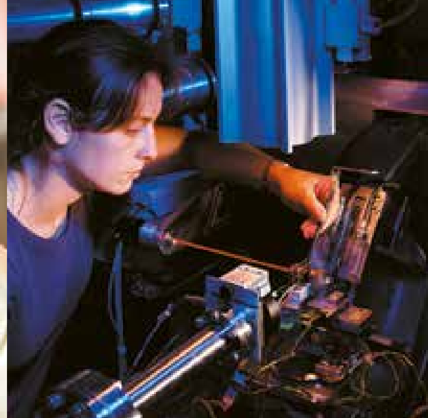
ISBN 978 94 625 8168 5
(Dutch)
ISBN 978 94 625 8199 9
(English)







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