Scientific report of the

Study Tour to Scandinavia

from 12-9-1993 till 30-9-1993

organised by JD van der Waals
Scandinavia study tour

Report of the study tour of
the students’ association
for applied physics
Johannes Diderik van der Waals
September 1993

Eindhoven University of Technology

February 1994
Scandinavia study tour

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Foreword

Studying is more than just absorbing knowledge. Studying ought to be an exploratory expedition through both theory and practice. A study tour abroad can give the inspiring experience of seeing how other people handle problems we also face in a different way. A study tour increases interest in ones studies and enlarges the knowledge about ones profession. These are the reasons why the Students’ Association for Applied Physics "Johannes Diderik van der Waals" organizes a study tour to foreign countries or territories each year. In 1993 we chose to visit Denmark and Sweden, because of their outstanding research in different fields of physics such as solid state, accelerator and particle physics. Our purpose was to construct a diverse programme with cultural and social elements in addition to the scientific basis of the tour.

It took us a year to prepare the trip. Moral and financial support as well as help in our efforts to get more acquainted with the specific subjects involved in our study tour had to be collected. The latter was found in professors within our university who supplied us with contacts in Scandinavia and prepared the participants for the study tour with special lectures. In order to get a better insight into the subjects also preparatory visits were organized. Several people active in politics or science at our university supported us morally by forming a Committee of Recommendation. For the financial support we owe thanks to our sponsors and the university.

Our efforts resulted in a three week study tour for sixteen students of the Eindhoven University of Technology accompanied by Prof. Dr. J.H. Wolter. The interesting visits, well prepared by most helpful hosts, the cultural encouragements of our attendant professor and the team spirit of the participants made the study tour to a lasting memory for everyone involved. I would like to thank all the people mentioned above for their contribution to our study tour. In particular I would like to thank my fellow members of the organizing committee for the pleasant cooperation and for the great time we had together. I hope this final report will succeed in describing our wonderful experiences and convey the enthusiasm of everyone.

Annemarie Bloot
chairman of the organizing committee
January 1994
### Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sponsors</td>
<td>3</td>
</tr>
<tr>
<td>Foreword</td>
<td>5</td>
</tr>
<tr>
<td>Board of Recommendation</td>
<td>9</td>
</tr>
<tr>
<td>Participants</td>
<td>10</td>
</tr>
<tr>
<td>Travel program</td>
<td>13</td>
</tr>
<tr>
<td>Preface</td>
<td>15</td>
</tr>
<tr>
<td>Philips Natuurkundig Laboratorium</td>
<td>17</td>
</tr>
<tr>
<td>NIKHEF Laboratory</td>
<td>21</td>
</tr>
<tr>
<td>PTT Research in Leidschendam</td>
<td>33</td>
</tr>
<tr>
<td>Odense University</td>
<td>39</td>
</tr>
<tr>
<td>Tele Danmark Research</td>
<td>45</td>
</tr>
<tr>
<td>The Niels Bohr Institute</td>
<td>51</td>
</tr>
<tr>
<td>H.C. Ørsted Laboratory</td>
<td>59</td>
</tr>
<tr>
<td>Cultural day in Copenhagen</td>
<td>67</td>
</tr>
<tr>
<td>Royal Institute of Technology</td>
<td>71</td>
</tr>
<tr>
<td>Alfvén Laboratory</td>
<td>77</td>
</tr>
<tr>
<td>Manne Siegbahn Laboratory</td>
<td>81</td>
</tr>
<tr>
<td>Cultural day in Stockholm</td>
<td>87</td>
</tr>
<tr>
<td>The Svedberg Laboratory</td>
<td>89</td>
</tr>
<tr>
<td>Scanditronix / GEMS PET Systems</td>
<td>101</td>
</tr>
<tr>
<td>Students' Association Värmlands</td>
<td>107</td>
</tr>
<tr>
<td>Uppsala Division of the Swedish Institute of Space Physics</td>
<td>109</td>
</tr>
<tr>
<td>Chalmers University of Technology</td>
<td>115</td>
</tr>
<tr>
<td>MAX - Laboratory</td>
<td>121</td>
</tr>
</tbody>
</table>
Participants

Organizing Committee

Harrie van Dijck (chairman)
René van de Veerdonk (secretary)
Marc Haast (treasurer)
Arno van Helvoort (vice-chairman)

Scientific guide

Dr. Mico Hirschberg (18 October - 28 October)
Prof. dr. ir. Daan Schram (29 October - 7 November)
    Hannie Schram (29 October - 7 November)

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Board of Recommendation

His Excellence Mr. J.A. Sillén
Swedish ambassador to the Netherlands

His Excellence Mr. T. Frost
Danish ambassador to the Netherlands

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Scandinavia study tour

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Coen Verschuren  
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Rob van Schayk  
(sponsoring)
Twan van Noije  
(treasurer)
Annemiek Kamp  
(hostels, travel)
Raymond Cuypers  
(visit program)

From left to right: Coen Verschuren, Raymond Cuypers, Annemiek Kamp, Annemarie Bloot, Rob van Schayk, Twan van Noije

Scientific guide

Prof. Dr. J.H. Wolter
Students

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Rob van Schayk, Johnny Vogels, Linda Verschuren, Ingrid Janssen,
Rob Kooijmans, Arthur Minnaert, Annemiek Kamp, Raymond Cuypers,
Remco Pasman, Annemarie Bloot, Arjan Vriens, Marc Bronzwaer
Scandinavia study tour

Travel program

Tue 2 Jun. Visit to Philips Natuurkundig Laboratorium, Eindhoven
Mon 30 Aug. Visit to NIKHEF, Amsterdam
Tue 31 Aug. Visit to PTT Research, Leidschendam

Sun 12 Sept. Journey from Eindhoven to Odense
Mon 13 Sept. Visit to Odense University
Tue 14 Sept. Visit to TDR
Wed 15 Sept. Visit to Niels Bohr Institute
Thu 16 Sept. Visit to H.C. Ørsted Laboratory
Fri 17 Sept. Cultural day in Copenhagen
Sat 18 Sept. Journey from Copenhagen to Huskvarna

Sun 19 Sept. Journey from Huskvarna to Stockholm
Mon 20 Sept. Visit to Royal Institute of Technology
Tue 21 Sept. morning: Visit to Alfvén Laboratory

afternoon: Visit to Manne Siegbahn Laboratory
Wed 22 Sept. Cultural day in Stockholm
Thu 23 Sept. Visit to The Svedberg Laboratory
Fri 24 Sept. morning: Visit to Scanditronix / GEMS PET Systems

evening: Visit to Students’ Association Värmlands
Sat 25 Sept. Visit to Uppsala Division of the Swedish Institute

of Space Physics

Sun 26 Sept. Journey from Uppsala to Göteborg
Mon 27 Sept. Visit to Chalmers University of Technology
Tue 28 Sept. Journey from Göteborg to Lund
Wed 29 Sept. Visit to MAX Laboratory
Thu 30 Sept. Journey from Lund to Eindhoven
Scandinavia study tour

Preface

Scandinavia 1993: a most enjoyable experience for all participants and unforgettable!
Almost three weeks of freedom from classes and enforced studies, freedom from tight schedules, freedom from established patterns.

Instead: ample time to think and to discuss physics in various fields, to generate ideas and to discover creativity again; also to realize that physics is one discipline not obeying facultary organizational structures and that curiosity and to play and have fun is the basis of successful studying and teaching.

The Van der Waals Students' Association succeeded in a remarkably well balanced scientific programme: plasma physics, solid state physics, accelerator physics, nuclear physics, theoretical physics and astrophysics. A wide range of topics was covered from highly specialized subjects like magneto-quantum transport in mesoscopic structures to the "superstring theory of everything". Altogether, this study trip represented an excellent sampler of physics in Denmark and Sweden.

This survey of the study tour does not need any introduction. The contributions, all of them written by participating students, are concise and clear. They testify the students' enthusiasm I have been facing during the journey.

Another big compliment must also be made: I am happy to express my admiration for the professional organization of the study tour and the assertive and natural leadership during the trip. Also I must mention the social activities, which always were "spontaneously planned" and organized, ranging from opera to sauna.

I am very grateful to the organizational team that they asked my company on their study tour. It has not only been an honour, it has been a great pleasure:

we had a wonderful time.

Joachim Wolter
Een autolamp die tegenliggers niet verblindt, maar die wel meer licht oplevert, dat was de vraag. Het resultaat is 'n lamp die, naast het zichtbare lichtspectrum, extra veel UV uitstraalt. Daardoor worden tot op grote afstand alle witte lijnen op het wegdek duidelijk zichtbaar. Kortom: een idee dat de verkeersveiligheid aanzienlijk kan verhogen.


Een bedrijf dat zo een positie aan de top van de markt ambieert, vraagt veel van z'n mensen. Daarom selecteren wij uitsluitend de besten. Qua studieresultaten en vakkennis.
Maar ook wat betreft creativiteit, inventiviteit, ondernemerschap, teamgeest, slagvaardigheid en een winnaarsmentaliteit.


WITH YOU - WE'LL MAKE IT.
Brief history

The Philips Company started in 1891. The technical development of its sole product, the incandescent lamp was done "alongside" the factory. In the rest of the world, the concept of a separate industrial research laboratory was only just emerging. In 1913, the decision was taken to open a physics laboratory (Philips Natuurkundig Laboratorium or "Natlab"). In 1914, Dr. G. Holst became the first true researcher in Philips. Under his leadership the Philips Research organization developed into a major center of technical competence and innovation.

Broadly speaking three periods of Philips Research can be distinguished. These are closely related to the historical development of the Philips Company and the general economical and political situation in the world at the time.

The first period (1914 until 1940-1945) was the period of growth and diversification. The research organization broadened its scope into work on radio receiving and transmission. Early work was also done into the development of television.

The second period (1946 until 1970) was the period of expansion. The research philosophy was characterized by the belief that research always pays off and that research automatically leads to products. There was room for every invention and only the sky was the limit. In this period, the research laboratories outside the Netherlands were founded, including those in the USA, Germany, the United Kingdom and France. The present international research set-up was established.

In the third period (1970 until present) industrial research has been tied much more closely to industrial activities. The emphasis has been shifted to research on systems; the research into integrated-circuit design and technology has played a very important role.

Introduction

At the Philips research laboratories 3000 people are working. About 2000 of them are working at Eindhoven. A third part of them are scientists.

The main lines of the research program at Eindhoven encompass: exploratory physics and chemistry, material science, display principles, audio systems,
television systems, perception, silicon IC process research, IC design, software engineering and computer architecture.

Reception at the Philips Research Laboratory

On our arrival at the Natlab, we were welcomed by Mr. J.M.D. Brink. The visit started with a short introduction to the Natlab by Mr. Brink. After that we have visited the following research groups: ionimplantation, Rutherford backscattering (RBS), Selective Ions Mass Spectroscopy (SIMS), Light from porous silicon, Metallic Multilayers (MEMULA), Oxidic Molecular Beam Epitaxy (MBE).

Ionimplantation

At the ionimplantation centre ions are implanted in metals, polymers and silicon. For this purpose there is a large hollow cathode source at high temperature. In order to get a pure beam of $\text{PF}_3$ ions the ions are selected in a mass selector build from superconducting magnets and an electrical field. After that the beam is accelerated in a linear accelerator (200 keV to 800 keV), focused by quadrupole magnets and after filtering split into two beams by a magnetic triplet.

The two beams are led into two different experiments. One of these is an automatic silicon doping unit, which is used for producing doped silicon for research at other groups within the Natlab. In the other unit all kinds of material can be doped with ions. Both of the experiments are situated in a clean room.

Ionimplantation can be used for the implantation of non-conducting material in conducting materials and vice versa. In this way it is possible to make parts of a conductor electrically "dead". Another application of ionimplantation is the improvement of the hardness of a material.

Rutherford back scattering

For the measurement of concentrations of elements in a thin layer Rutherford backscattering (RBS) is used. With a Van de Graaff generator $\text{He}^{2+}$ ions are produced. These ions are accelerated in a vacuum system to 2 MeV. After that a pure beam is
Scandinavia study tour

made by an energy selector and focusing quadrupoles. This beam is aimed at the sample.
At collisions from the ions with the sample there is a loss of energy due to the transfer of momentum from the ions to the lattice of the thin layer. By measuring the energy of the backscattered beam at different angles it is possible by means of a multi channel analyser to make an energy spectrum. From the energy spectrum the concentration of each element can be derived.
The resolution of the RBS measurements is about 100 Å. With RBS it is possible to determine the concentration of pollutions in samples and the crystal structure of crystalline solids.

Selective Ions Mass Spectroscopy

With Selective Ions Mass Spectroscopy (SIMS) it is possible to measure the concentrations of elements dependent on the depth of the sample. A beam of Ce- or O-ions scans the sample a hundred times per second. In this way the top layer of the sample is ionized, and the ions are flung from the surface. After this the concentration of the different elements in the layer is determined by the use of mass spectroscopy. By repeating this for the duration of the sample an overview of the concentrations of the elements in the different layers of the sample is constructed.

SIMS can be used for the determination of the location of junctions in semiconductor devices. A disadvantage of SIMS with regard to RBS is the destructive effect on the material of interest.

Light from porous silicon

Porous silicon is made by treating normal silicon with acids. This way potential wells are created, because the dimensions of the porous structure are those of the De Broglie wavelength of electrons. One of the special properties of porous silicon is that the crystal emits visible light at the decay from an exited state.
The applications of porous silicon can be: lightsource, flat displays and optical communications. Essential for all these applications is the electrically stimulated excitation to the excited state.
Molecular Beam Epitaxy

Oxidic Molecular Beam Epitaxy (Oxi-MBE) enables to grow single layers of a specified oxidic compound on a substrate. In this case multilayers of magnetic oxides (Fe₃O₄ / CoO) are grown.

The metal flux sources are shuttered from the substrate and by opening the shutter, the metal atoms will adsorb on the substrate and subsequently be oxidized by the coadsorbed oxygen. This yields the desired oxide. Changing of metal flux source, deposition temperature and oxygen pressure allows formation of a different oxide which then can be grown on top of the previous layer thereby forming a heterostructure or, if repeated, a multilayer.

In this group MBE is used to make magnetic field sensors, multilayers, oxidic conductors and magnetically "hard" materials.

Metallic Multilayers

At the Metallic Multilayers-group (MEMULA) metallic multilayers are grown by MBE and researched to find the combination of materials with the best properties. The substrates are critically examined. An analysis of the grown multilayer is performed by photo-electron spectroscopy. The surface structure of the sample is checked by low energy electron diffraction. The following magnetical properties, magnetoresistance and magnetical optical effects are also measured. Applications of metallic multilayers are e.g. the DCC-recorder, the development of a magnetic field sensor (by means of the magneto-resistance effect) and improvement of information storage.

Acknowledgements

After a very interesting afternoon we thanked Mr. Brink for the visit during an informal meeting with other members of the Natlab who showed us their work at the research laboratory.
NIKHEF Laboratory
August 30, 1993
Rob van Schaijk and Raymond Cuypers

Introduction

The National Institute for Nuclear Physics and High-Energy Physics (NIKHEF) is a joint venture of FOM (Foundation for Fundamental Research on Matter), the University of Amsterdam, the Catholic University of Nijmegen, the Free University of Amsterdam and the University of Utrecht. The NIKHEF laboratory is located at the Science Research Centre Watergraafsmeer (WCW) in Amsterdam. NIKHEF has two sections called NIKHEF-H and NIKHEF-K where research is done on high-energy physics and nuclear physics respectively. The laboratory has at its disposal a 700 MeV linac called MEA (Medium Energy Accelerator) and a storage ring, the Amsterdam Pulse Stretcher (AmPS). NIKHEF also participates in projects with CERN in Geneva and DESY in Hamburg.

After two lectures about NIKHEF, the AmPS storage ring facility, scattering experiments and (e,e'p) reactions we were guided along the experimental setup i.e. MEA and AmPS.

The MEA linear accelerator

MEA consists of 180 m vacuum tube equipped with 13 waveguide accelerator sections, many quadrupole and other magnets, an Energy Spectrum Compressor (ESC) and a 400 keV electron gun.

Quadrupole Magnets

Quadrupole magnets are used for focusing a beam of charged particles. When the beam is directed along the z-axis, the magnetic field in the magnet is of the form:

\[
\begin{align*}
B_x &= by \\
B_y &= bx \\
B_z &= 0
\end{align*}
\]  

(1)

with \(B_x,B_y,B_z\) the axial components of the magnetic field vector, \(x,y\) the coordinates and \(b\) a constant. The components of the Lorentz force \(\vec{F} = q(\vec{v} \times \vec{B})\) for a
particle with charge $q$ and velocity $\vec{v}$ satisfy:

$$
F_x = -qv_z B_y = -qv_z b x = -k x \\
F_y = -qv_z B_x = qv_z b y = k y
$$

$v_z$ is the velocity in the z-direction and $k$ is a constant defined by (2). If $k$ is positive, particles with an $x$-displacement will feel a force toward the $x=0$ plane ($F_x$) and particles with a $y$-displacement will feel a repelling force ($F_y$) from the $y=0$ plane. So the beam will be focused in the $x$-direction and defocused in the $y$-direction. When two quadropole lenses are placed behind each other so that the first focuses in the $x$-direction and the second in the $y$-direction and vice versa, then the overall effect will be a narrowing of the beam (see fig. 1).

### Waveguide accelerator

A waveguide accelerator is made up of several cavities which are constructed to be resonant with a transverse magnetic mode ($TM_{010}$) of an electromagnetic wave. The $TM_{010}$ mode is a solution of the Maxwell equations for an electromagnetic wave confined in a waveguide; in contrast with a wave in free space, a TM-wave has a component of the electric field in the propagation direction. This field component also oscillates. At NIKHEF the cavities operate in traveling wave mode, this is achieved by terminating the waveguide with a non-reflective end.

Electrons with an energy of 1 MeV already approach the speed of light. If these relativistic electrons gain energy, the increase in speed is negligible and only the mass will increase. When the velocity is (almost) constant, an electron can gain energy by phase-locking a traveling wave (in TM mode) to it; that is, the electron velocity is the same as the phase velocity of the wave. A phase-locked electron will experience a constant electric field in the propagation direction and if the timing is right the particle will accelerate.

Normally the phase velocity in a waveguide exceeds lightspeed but by placing metal irises periodically in the waveguide the velocity can be brought down (see fig. 2).

Because the electrons approach lightspeed, it need not be brought down much so there is little loss of power. With this setup the mode with the matching velocity will be enhanced compared to other modes.
Fig. 1: a) Cross section of quadropole lens. b) Two lenses in series give a net focusing effect. c) An optical analogy.
The MEA linac operates at a frequency of 2.856 GHz and the microwave power is supplied by klystrons which produce a short intense burst (5 µs width) of microwave energy, up to 400 times per second. The average power output is about 100 kW. With this configuration the electrons gain energy up to 700 MeV.

The AmPS storage ring

After leaving MEA the electrons are bent into the AmPS storage ring (Amsterdam Pulse Stretcher). The ring is equipped with one internal waveguide accelerator, an internal gasjet target chamber and is connected via a special extraction magnet to an external target chamber. Due to the additional accelerator section an energy of 900 MeV can be reached.

Fig. 2: a) Section through an iris-loaded waveguide. b) cyl. waveguide el. field for standing wave, c) for travelling wave.
Scandinavia study tour

Fig. 3: Layout of the AmPS storage ring with (a) the internal gasjet chamber and (b) the external target chamber.

The ring can operate in two ways: as a storage ring or in the stretcher mode.

1) In the storage mode all injected current is stored in the ring. The target is a gasjet so that as little electrons as possible are lost. In this way a current can be reached up to 150 mA and a power up to 50 kW.

2) In the stretcher mode the ring is first filled with electrons from MEA before the extraction starts. MEA provides the ring with electrons that are bunched. The injection current has a dutyfactor of approximately 1%.

This dutyfactor is defined by:

\[
dutyfactor = \frac{\text{time beam is on}}{\text{total real time}} \cdot 100\%
\]  

(3)

After the storage ring has been filled, a ‘smart’ extraction magnet produces a beam with a smoothened current distribution yielding a dutyfactor up to 90% (see fig. 4). The extracted current will be as high as 20 μA and this beam is sent to the external target chamber where many scintillators and other counters detect the reaction products.
Advantages of the AmPS ring

In the old situation detectors would be blinded because each 3 ms a short and intense pulse (several MW during 30 μs) hits the target and too many particles are scattered at once (see fig. 5). With AmPS the beam current distribution is stretched out reducing the peak intensity to several kiloWatts so that much more sensitive measurements can be performed with a much better signal-to-noise ratio. Due to
Scandinavia study tour

this high duty factor of 90% and high current (20 μA), it is now possible to investigate very rare reactions. An example is the investigation of the propagation of the first excited state of the nucleon (the Δ-resonance) in the nucleus.

Fig. 5: Comparison between the old and new situation where detectors are not blinded anymore.

Detection methods and equipment

The external target chamber in which a ladder of target foils is mounted, is surrounded by two magnetic spectrometers, and possibly a hadron detector (i.e. a large solid-angle detection system for protons), and possibly a neutron polarimeter (the High Acceptance Recoil Polarimeter, HARP).

The Hadron-detector consists of a Multiwire Proportional Counter (MWPC) and six layers of scintillators (see fig. 6). A scintillator consists of a piece of transparent plastic (or other material) inside a light-tight box with highly reflective inner walls and is connected to a photomultiplier via a window.

With a scintillator charged particles can be detected: a charged particle passing through the detector leaves a trace of excited atoms which emit light when falling back to the ground state. Because the scintillator is transparent for this light, the photons reach and hit a photo-cathode where they release electrons due to the photo-electric effect. This signal is then amplified: the electrons are accelerated
over a potential before hitting a new plate (dynode) where they release more electrons. This is repeated several times (see fig. 7). The number of photons released by the passing particle is a measure for its energy and if more photons hit the cathode a stronger signal is created so the energy of the particle can be measured. By arranging the scintillators in layers of vertical and horizontal strips information can be retrieved about the location where the particle passed through.

The MWPC is a gasfilled wire chamber in which a high voltage is applied over a plane of wires and a plate electrode (see fig. 8). A passing particle will leave a trace of ionized gas and electrons and this will, on its turn, lead to an electric signal to one of the wires. The current through the wire is recorded. If the high voltage is triggered by a scintillator the background noise is much reduced and also
Fig. 7: A schematic presentation of a scintillation detector.

Fig. 8: A schematic representation of a section through a spark chamber with a high-resolution wire plane.

the location of the signal on the wire can be determined by measuring the time it takes for the electrical pulse to travel down the line.
HARP consists of a LH$_2$ converter, 6 layers of MWPCs and ΔE and E plastic scintillator telescopes surrounded by 6 cm of lead-steel. The HARP-detector is designed to detect neutrons by converting the neutrons to protons in the LH$_2$-detector and detecting the protons in the wire chambers and scintillators. It is also possible to measure the polarization of the incident neutron by evaluating the difference between 'up' and 'down' scatterings.

**Experiments carried out at NIKHEF Amsterdam**

**Scattering experiment**

When electrons are scattered from a nucleus the scattered electrons can be counted as a function of angle. This yields an interference pattern. A mathematical operation (similar to a Fourier Analysis) gives the charge density as a function of the radius (see fig. 10).

**Fast protons in nuclei**

If electrons are scattered on a nucleus and a proton is knocked out, the momentum and energy of the proton can be determined. The momentum of the incident electron ($e_0$) is known and the momentum of the scattered electron ($e'$) and recoil proton ($p'$) can be measured. This is done by coincidence measurement of both particles. The law of conservation of momentum yields:
Fig. 10: Charge distribution in Si.

\[ P_m = e_0 - e' - p' \]  \hspace{1cm} (4)

where \( P_m \) is the 'missing' momentum or the proton momentum before the collision. Similarly the missing energy can be calculated from:

\[ E_m = E_0 - E' - T_p - T_{A-1} \]  \hspace{1cm} (5)

where \( E' \), \( T_p \) and \( T_{A-1} \) are the energies of the scattered electron, outgoing proton and residual nucleus respectively and \( E_0 \) is the initial energy of the electron. The result of such a measurement for \(^{12}\text{C}\) is displayed in fig. 12.

**Delta-resonance**

When an electron hits a proton inside a nucleus it can turn around the spin of one of its constituent quarks yielding a \( \Delta \)-particle. This particle can be regarded as an excited state of a proton. Most of the time (99.4% probability) it will decay to a pion and a proton or neutron. By means of coincidence measurement of pions and protons, the excitation of a \( \Delta \) can be identified.
Fig. 12: The measured momentum distribution in $^{12}$C. Illustrated is the number of particles as a function of the 'missing' momentum.

Acknowledgements

Finally we would like to thank Jacques Visser for the organization, thanks also to the lecturers, the people who guided us through the building and to all the others who made this interesting afternoon possible.
Introduction

As a preparation for the visit to TFL, the Danish research institute for telecommunication in Copenhagen, the participants of the study tour to Scandinavia visited the research institute of Royal PTT Nederland N.V., PTT Research in Leidschendam. Mrs. Smeele outlined the main activities in research and the organizational structure of Royal PTT Nederland N.V. Royal PTT Nederland N.V. relies on PTT Research for high level research in information and communication services in the Netherlands. The organizational chart of PTT Research is shown in the figure 1.

PTT Research presented five different examples of research projects on video. First there was the IN-services, intelligent networks. One could think of UPT, universal personal telecommunication, and of PST, performance simulation tool. The second example is the project-teams, which are occupied with the development of the postcodereader and the Inmarsat-system. The last mentioned project contains e.g. the e-mail-network.

Furthermore there are the two European research programmes RACE, Research and development in Advanced Communication technologies in Europe, and ESPRIT, European Strategic Programme of Research and development in Information Technologies, in which PTT Research participates successfully. These programmes were set up to provide the European industry with a technological springboard for the competitive battle with the United States and Japan. The fourth example was in the ISDN, Integrated Services Digital Network. Important in this case is the wide band technology, which makes possible megabit-communication such as multi-image telephone and other information-dense communications. The last example is hypertext, new development in the megabit-communication.

Integrated optics.

The research in Integrated Optics was presented by Ir. Jørgen W. Pedersen. In future this technology will realize optical fiber links between chips. The signal in optical fibers can have a bandwidth much wider than in an electrical wire, so that
an optical fiber can transport much more information than an electrical wire. To make this technique profitable, development of cheap micron scale lasers and detectors is necessary. These lasers and these detectors, photodiodes, are integrated on chips made on InP substrates. The lasers are made of $\text{In}_{1-x}\text{Ga}_x\text{As}_y\text{P}_{1-y}$. The relation $x = x(y)$ is determined by the lattice constant of the structure, which needs to be the same as in InP. The experimentally determined relation between $y$ and the wavelength of the emitted light, shown in figure 2, appears to be nearly linear. The loss of signal in optical fiber is at minimum at a lightwavelength of $1.3\mu\text{m}$ or $1.5\mu\text{m}$, so that $y$ should either be 0.53 or 0.87.

In order to convey more information simultaneously in an optical communication network, it is important to couple and split signals in a controlled way. A schematic set-up of a so-called 3dB-coupler, consisting of a mixing, coupling and splitting section, is given in figure 3a. In this case we assume the mixing is done with an asymmetric Y-junction of which only one branch is used. In figure 3b the principle of an asymmetric Y-junction is outlined. The incoming signal consists of the fundamental and the first order modus. It depends on the width $W$ of the waveguide and
the angle between the two splitting parts which order of the modus will exist in the waveguide. In the bimodal coupler section only two orders, the fundamental and the first order modus, propagating at different velocities, can exist. The length of the coupling section affects the splitting of the orders into the different channels. This splitting is independent of the polarization modi.

Figure 3a, b, c: Optical signal controlling elements.

In the symmetric splitting section the signal is divided into two equal parts. This is the reason why this component is also called a "50/50 coupler". The total loss of power in this optical device is 75%. At the mixing in the coupling section half the power is lost and at the splitting section half the remaining power is lost.

There are two kinds of polarization, TM and TE, which can be splitted in a polarization splitter. A polarization splitter is in fact a modus converter and a Y-junction in serie. The modus converter contains a block structure in which the zero order modus of the TM polarization is converted into a first order modus signal, shown in figure 3c. The Y-junction contains two branches of different sizes, so that it splits the fundamental and first order modus of the incoming signal. Besides, the signal of the first order is converted into a signal of the fundamental order modus again.
Optical transmitters within integrated networks are grown with InP channels and walls of a material, like GaAs, which has a higher refractive index than InP. In long fiber connections light is lost to a maximum of about 0.1% of the light due to the effect of Rayleigh backscattering and reflection at irregularities of the material. A polarization splitter is used for polarization multiplexing in optical networks. Then the signal in one direction is TE polarized and the returning signal is TM polarized. The polarization splitter mixes and splits these signals.

In the near future PTT Research will stop the research in the optical components and will buy the devices from other companies.

**Optical amplifiers**

Drs. Oscar J. Koning presented the research in optical amplifiers in particular. In some optical systems optical amplifiers are used to compensate losses in fibers. Optical amplifiers are also used for boosting the transmitter output power of signals before entering a network. There are two types of optical amplifiers: semiconductor laser amplifiers and fiber amplifiers. Fiber amplifiers appear to be most suitable in telecommunication. Semiconductor devices are mainly applicable for optical signal processing purposes. There are three types of fiber amplifiers: Raman amplifiers, Brillouin amplifiers and rare earth doped amplifiers. Only the rare earth doped amplifiers are already in commercial use. These amplifiers work on behalf of stimulated emission of light after absorption by the doping atoms. The most commonly used dope is Erbium (1.5μm emission) beside Praesodymium and Neodymium (both 1.3μm emission). By aiming a pump laser on dope atoms, electrons are pumped to excited states. The incoming signal is also tuned to the dope atoms, which activates a mechanism of stimulated emission between two energy levels. That is the way how the signal is gained. Practically an Erbium amplifier produces a quantum noise level, caused by the spontaneous emission, depending on the level of the incoming signal. If the incoming signal is too strong, the optical amplifier is saturated. To reach the optimum signal to noise ratio, careful dimensioning and proper adjustment of the optical amplifiers within the network is important. Due to the high pumping power (>10 mW) non-linear effects are very important in their fiber amplifier and are in particular studied in detail.
Drs. Koning concluded that the specifications for optical amplifiers are very complex and their positions makes this research project necessary. Drs. Koning ended his lecture with an experiment, see figure 4. Here he showed how the signal in a fiber can disappear into the noise when the amplifier input signal is taken too low. Besides, he demonstrated the saturation of the amplifier.

Acknowledgements

After the very interesting visit and a tasty lunch we thanked Mrs. Smeele, Ir. J.W. Pedersen and Drs. O.J. Koning for the most interesting lectures at PTT Research.
The graduate school on

COMMUNICATION TECHNOLOGIES
BASIC RESEARCH AND APPLICATIONS

ELECTRICAL ENGINEERING
CHEMISTRY
PHYSICS

Introduction

On Monday the 13th of September we visited Odense University. At 9.00 am we were welcomed by Peter Sigmund, who told us something about the university and what we were going to hear and see.

This university started out as a medical faculty, so biology and chemistry were important. Nowadays the university has 10,000 students and a Physics Department with 13 staff members. Most of the students live on campus.

Surface Physics

Going from bulk to vacuum, you encounter different electronic states. As a simple thought-experiment shows, it costs energy to create a surface (bonds are broken, compare with surface tension in a liquid).

The number of direct neighbour-atoms can change from 0 (free) to 6 (in bulk) and with that the physical properties. The different possibilities on or near the surface are shown in the figure below.

In order to study interfaces diffraction experiments are used, e.g. electron spectroscopy. Because you want to look at one monolayer (0 - 5 Å) you need a strong interaction of the electron with the atoms. This means you need electrons with an energy of approximately 100 eV. At a lower energy the electrons haven’t got enough energy to interact with the (surface) atoms, and at a higher energy the electrons penetrate deep into the material and surface-information is lost.

The Scanning Tunneling Microscope is an almost needed tool to know what is going on on an atomic scale.

You can obtain information about the electronic structure of the surface by using photon induced electron emission (photo-electric effect). Striking the surface with a polarized photonbeam, electrons are emitted. By measuring their kinetic energy and
the wave vector (plane-parallel component) as a function of the detector angle you can determine the dispersion relation. To be able to measure core electrons you need synchrotron radiation. Magnesium and aluminium X-ray tubes are also used.

This technique, also called XPS (X-ray photoelectron spectroscopy), is used to study thin films (concentration, distribution of atoms). The reasons of interest in thin film growth are: 1. electrical contact to a device (e.g. Si); 2. coatings (protective or decorative); 3. prestep for interdiffusion of layers; 4. monolayers and sandwiches.

The different growth-structures can be divided into three groups: 1. well ordered in layers (perfect match of substrate and adsorbate, therefore very rare); 2. island formation (much more typical); 3. interdiffusion systems (atoms diffuse in substrate, even at room temperature).

By making assumptions on the distribution of the atoms you can analyse the (XPS) data and determine if the assumptions are correct. It is also possible to 'check' the amount of island growth.

After the lectures we visited two laboratories. In the first laboratory electronic prints were investigated. The problems in making the connectors smaller and smaller are finding the optimal gold-thickness and the right process.

The prints are examined layer by layer by sputtering with $\text{Ar}^+$ (1 - 3 keV) and detecting the Auger-electrons. Details can be seen by sweeping the electronbeam across the sample. The high background is removed by differentiating the signal. By measuring the intensity of the electrons during the scan you obtain a picture of the sample with a resolution of $0.10 \text{ mm}$. This picture can then be used to aim the beam to an interesting area and make an Auger spectrum.
Scandinavia study tour

In the other laboratory we heard something about the conversion of acetylene to benzene on Pd/Ru(0001). The reason for this project is that the process is well used in industry and that Pd is very expensive.

The different experiments used are:
- thermal desorption spectroscopy (different temperature, different signal). You see two peaks, belonging to two ways of conversion.
- low energy electrons.
- XPS. Here gold is (gradually) deposited on the sample in order to investigate how large the active area of Pd must be.

Laser Physics

After lunch we had a lecture on terahertz (femto-second) spectroscopy. For this technique you need a femtosecond-laser, a colliding pulse mode-locked (CPM) laser. This laser uses a blue pumplaser, lots of mirrors, dyes (transparant at high intensity!) and a prism section to compensate for line-broadening (Heisenberg uncertainty principle).

In order to measure femtosecond pulses you need an optical technique (electronics are too slow). A way to do this is by splitting the beam with a prism, delaying one beam and focusing the beams on a non-linear crystal (see the figure below). This crystal doubles the frequency of two coherent pulses. So, by measuring the (blue) intensity as a function of ΔL you can determine the length of the pulse (Δt = ΔL/c).

With these very short pulses and measuring techniques you can measure the rotation period of a 'classical' electron (n = 60, 61, ..., 90) in hydrogen. Other possibilities are research on molecular processes, such as the dissociation of hydrogen-peroxid. Another application is the creation of ultrashort electrical pulses (100 fs).

Ion Beam Physics

The first lecture on this subject is about stopping of swift charged particles. A measure for this stopping is given by the stopping power, which is approximately (minus) the energy loss divided by the distance.
The basic theoretical tool is the Rutherford cross section. For the stopping power it gives
\[ \frac{dE}{dx} = \frac{4\pi (Z \, e^2)^2}{mV^2} \rho \cdot L \]
with \( L = \ln(b_{\text{max}}/b_{\text{min}}) \) (b is the impact parameter). Using for \( b_{\text{max}} \) the adiabatic cut-off and for \( b_{\text{min}} \) the QM-limit you obtain
\[ L = \ln\left(\frac{2mV^2}{\hbar \omega}\right) \]

According to Bethe (1930) \( L_0 = \ln \left(\frac{2mV^2}{I}\right) \), with I the mean excitation energy (determined from experiment). The stopping power as a function of energy (Bethe) is given in the figure.

There are three theoretical corrections:
I. shell-correction: non-zero orbital motion of the electrons.
II. higher order: \( Z^3 \) correction (BARKAS-effect) because of polarisation.
III. relativistic corrections: \( v/c \) approaches 1.

The last lecture of the day was about sputtering by ion bombardment. The simplest way to do this (erode material) is by collision cascades. This is used in the laboratories. Often Ar-ions are used (keV) to sputter the materials. It is found that approximately one Ar ion removes one atom.
Scandinavia study tour

Sputtering is also found in space: satellites are being bombarded with particles, planets and moons erode because of the solar wind. Radioactivity also causes sputtering (fast particles).

It is used to clean or etch samples in a controlled way, for example astronomical mirrors.

A problem in describing the process of sputtering is that isotopes react in a different way. Prof. P. Sigmund made a prediction in 1973:

with c the concentration of isotope a or b, M the mass and m=0.1

\[ \frac{Y_a}{Y_b} = \left( \frac{M_b}{M_a} \right)^{2m} \left( \frac{c_a}{c_b} \right) \]

The deviation of the equation by a factor 2 or 3 is being investigated by Prof. H. Brongersma (Eindhoven).

Acknowledgements

We would like to thank prof. P. Sigmund for the organization of this visit. We also owe thanks to the lecturers and the guides during our visit to Odense University for the very interesting start of our study tour.
Er wordt nog wel eens gedacht dat je als academicus bij Shell verplicht bent om voor een aantal jaren naar het buitenland te vertrekken. Waar en niet waar. Dat hangt er namelijk helemaal vanaf welke divisie van Shell je gaat werken. Als pas afgestudeerd academicus start je bij Shell vrijwel altijd in het vakgebied waarop je studie zich richtte. "Logisch", zul je zeggen, "daarvoor heb ik een bepaalde studierichting gekozen".

Zeker, maar na zo’n twee tot vier jaar verander je in principe weer van baan. "Jobrotation" noemen wij dat. Overigens, je bepaalt hierbij voor ‘n groot gedeelte zelf wat je wilt gaan doen. En als het gaat om wáár je wilt werken, houden we terdege rekening met je voorkeur. We gaan er namelijk vanuit dat je alleen dan tot de beste prestaties komt, wanneer je je gelukkig voelt met de omgeving en de functie waarin je werkzaam bent.


Maar al is Shell een internationaal georiënteerd concern, ook in Nederland kun je een prachtige carrière opbouwen. Laat daar geen misverstand over bestaan!

Wil je echter je horizon verruimen in de meest letterlijke zin, dan staat de deur bij onze vestigingen in 120 landen elders in de wereld altijd voor je open.

Voor meer informatie over een nationale of internationale loopbaan kun je je wenden tot Shell Internationale Petroleum Maatschappij B.V. (afdeling HREH), Postbus 162, 2501 AN Den Haag.
Tele Danmark Research

Introduction

TDR is the joint research laboratory for Copenhagen Telephone Company, Jutland Telephone, Funen Telephone, South Jutland Telecom, and the international operator Telecom Denmark Ltd. The objective of TDR is to carry out strategic research on topics which are considered to be of importance for the long-term development of the telecommunications network in Denmark.

TDR concentrates the resources on the following five areas:

- Telecommunication Systems, in particular transport methods and signalling principles in broadband networks.

- Software Engineering, covering the application of formal methods for specification, definition, development, verification and test of telecom software systems. The work also covers studies of open networks- and service architectures.

- Optical Communications, comprising fabrication technology (MOVPE), optoelectronic components, femtosecond pulse measurement techniques, and optical communication systems.

- Signal Processing, particularly methods for coding of speech and of moving pictures with the purpose of making efficient use of available channel capacity.

- Social Science, users needs and future telecomservice, international and structural development of the telecom sector, broadband services and picture-based media.
Fabrication of semiconductor lasers.

The basic principle of a semiconductor laser is as follows. An active region of semiconductor material is placed between layers of p-doped and n-doped material. The active region is the place where electrons and holes, created by a bias current, recombine. This recombination is associated with the emission of a photon, with an energy approximately equal to the band gap.

The front and back side of the material are cleaved perpendicularly and act as partial mirrors, so the photons pass the active region several times. The photons then stimulate further recombination of electron-hole pairs and a laser effect is born. The lattice constant of the layers has to be equal, so a good choice of material is an InGaAs - InP system.

For crystal growth a method called MOVPE is used, Metal Organic Vapour Phase Epitaxy. A substrate is installed in a space through which a gasflow is lead. At the right temperature and pressure the gas is deposited on the substrate. In this manner it is possible to grow layers with an interface abruptness of only 2 or 3 monolayers. The material composition can be deduced by measuring the Bragg angles using X-ray diffraction.

The Fabry-Perot laser transmits light with different wavelengths. To isolate one wavelength a grating is made in the layer above the active layer. The electromagnetic field with the right frequency is scattered from this grating, thereby isolating the mode with this frequency. This kind of laser is called a distributed feedback laser. The used grating has a period of 235 nm.
Characterization of semiconductor lasers.
(Thorkild Franck, student)

The topics of interest are the gain spectra $G(\lambda, I)$, where $I$ is the bias current through the laserdiode and $\lambda$ is the wavelength. The carrier density $N(I)$ is another important value. Other characteristics are differential gain, internal loss, recombination coefficients, transparency density of carriers and change in refractive index.

Currently an investigation has been done at a laserdiode with 7 i-InGaAs quantum wells. It takes 12 hours for one measurement and that produces 5 to 10 Mb of data. The intensity vs. wavelength of the Fabry-Perot spectrum is measured for a wide-range wavelength span. The diode is biased below threshold, so stimulated emission can be neglected. This makes it possible to presume a simple model for the Fabry-Perot spectrum.

![Fabry-Perot spectrum](image)

*Fig. 3: Fabry-Perot spectrum*

The measured Fabry-Perot spectrum is mixed with noise, especially for low intensities. To make an automatic calculation that overcomes the noise a Fourier transformation is imposed. All frequencies above the main frequency corresponding to the spacing between maxima in intensity are discarded. A backward Fourier transformation then yields a smooth picture, in which the ratio between maxima
and minima can be derived. This ratio yields the net mode gain, which is the material gain minus the internal loss.

![Graph](image)

*Fig. 4: comparison of trace and interpolation methods*

**Carrier dynamics in semiconductor structures.**

Electronics limit the transmission capacity, so optical devices must be used. By using this fiber it might be possible to design an optical switch which is ultrafast and driven by a semiconductor laser.

In order to observe the carrier dynamics of small semiconductor devices one needs to look at time scales of around a hundred femtoseconds. Electrical techniques cannot reach these kinds of short timeconstants. Therefore a short optical pulse is used. TDR has built a femtosecond lasersystem, to create these pulses. Normal solid state lasers can produce laser pulses down into the picosecond range. A compression technique is needed to shorten this pulse, in this case the so called additive pulse modelocking (APM) technique. A solid state (Nd:YLF) laser producing pulses is used to pump a Colour Center laser. A beam splitter is used to couple this laser cavity to a secondary fiber cavity. The fiber has nonlinear optical properties for light of this frequency and creates a chirped pulse, this is a pulse
Scandinavia study tour

with enlarged bandwidth. In the primary cavity this chirped pulse constructively interferes with the main pulse and here the ultrashort pulse is made. For this constructive interference the cavities have to be made with interferometric precision. In this way pulses are generated with temporal spacings of about 10 nanoseconds.

![Diagram of APM lasersystem]

The pulse made by this laser is then split into two pulses: a pump pulse and a probe pulse. The pulses are perpendicularly polarized in order to be able to separate them after going through the sample.

The gain change of the sample as scanned by the probe pulse can then be considered a summation of four effects:

- carrier density, density of present holes and electrons.
- spectral hole burning, the electron density is reduced at the energy level of the photons; this leaves a nonthermal energy distribution
- carrier heating, the electrons scatter against other electrons to level the energy distribution created by spectral hole burning, this is a process that doesn’t produce thermal equilibrium as well.
- two photon absorption, an atom absorbs two photons at the same time and emits only one photon after a certain time.

The last three processes lead to nonlinear gain effects in semiconductor lasers.
**Multi-gigabit optical communication systems.**

(Olofsson Lars)

The present-day optical communication systems demand more and more for higher bandwidths and larger transmission distances.

An optical communication system consists of at least four components: a transmitter (semiconductor laser), a transmission medium (optical fiber), an amplifier (erbium-doped fiber amplifier) and a detector (PIN diode).

When you send lightbeams with different wavelengths through a fiber, the least fiber loss appears at wavelengths between 1.5 and 1.6 μm. The frequencies which belong to these wavelengths lie between 200 and 190 THz. This gives a bandwidth of 10 THz. With the use of an erbium-doped fiber amplifier one can compensate the fiber loss and so transmit light over long distances. This amplifier works very well for wavelengths between 1.53 and 1.57 μm.

It is desirable to transport lots of information at the same time through one fiber. This is possible with optical multiplexing:

- polarization multiplexing, two lasers send their signal perpendicularly polarized through the fiber.
- time division multiplexing, the fiber is open to one pulse train at a time, but the total time is shared between different pulse trains.
- wavelength multiplexing, the fiber is shared between lasers emitting at different wavelengths.

So information transfer, at multi-Giga-Bit/s rates, over Mega-meters, to millions of subscribers, is made possible by a large optical carrier frequency, low loss fibers and optical transmitters, amplifiers etc.

**Acknowledgements**

Finally we would like to thank Mr. O. Albrektsen for the organization of this very interesting visit, Mr. J. Hanberg, Mr. T. Franck, Mr. J. Mørk and Mr. L. Olofsson for the lectures and all the other persons who contributed to the visit.
Introduction

The Niels Bohr Institute (NBI) was founded in Copenhagen in 1921 as Institut For Teoretisk Fysik. At the institute theorists as well as experimentalists are working on nuclear, high energy and astrophysics. Also research is done into complex systems. In the late fifties Nordita was founded, where research is concentrated on nuclear, particle, astrophysics and solid state physics. Nordita co-operates strongly with the NBI. Since 1993 the NBI is part of a larger organization, the Niels Bohr Institute for Astronomy, Physics and Geophysics (NBI f APG). In this organization is also co-operating the H.C. Ørsted Laboratory, which used to be an independent university in Copenhagen.

Jacob Bondorf, Theoretical Nuclear Physics

Modeling of the nucleus has passed different stages.

The first model of the nucleus was proposed by Niels Bohr himself as the compound nucleus in 1936. He studied the events arising from a collision between a neutron and the nucleus. Imagine a shallow basin with a number of billiard balls in it. If the basin was empty, then upon striking a ball from the outside, it would go down one slope and pass out on the opposite side with its original velocity. But with other balls in the basin, there would not be a free passage of this kind. The struck ball would first share its energy with one of the balls in the basin. These two would similarly share their energies with others and so on until the original kinetic energy was divided among all the balls. If the basin and the balls are regarded as perfectly smooth and elastic, the collisions would continue until the kinetic energy happens again to be concentrated at a ball close to the edge. This ball would then escape from the basin and the remainder of the balls would be left with insufficient total energy for any of them to escape.

In 1949 the shell model of the nucleus was proposed by Mayer and Jensen. In this model protons and neutrons can occupy different energy levels independently of each other.
B. Mottelson and Aage Bohr, son of Niels and like his father in 1922 Nobel Prize winner in physics, proposed the deformed nucleus model in 1952. In this model collective rotational movement occurs in nuclei with nonspherical equilibrium shapes.

Also in heavy ion physics different stages can be distinguished. In 1956 Coulomb excitation was examined. In this case there is no contact between the two colliding nuclei. Later in 1970 the deep inelastic process, which can be demonstrated by oil drops, was studied. Finally relativistic collisions were studied at Berkeley in 1972.

Nuclear physics in the nineties and beyond will experience different developments:

1) big international technical installations (CERN, Brookhaven)
2) a closer contact with particle physics; a mix of excitations of nuclei with nucleons
3) a closer contact with astrophysics with respect to nuclear synthesis, supernovae and neutronstars, and the early universe
4) at lower energy studies of complex phenomena e.g. multi-particle correlations.

Clive Ellegaard, Experimental Nuclear Physics

The Niels Bohr Institute uses for nuclear physics two different accelerators. Both are standing forty kilometers away from the NBI.

The first accelerator is a tandem accelerator. This tandem accelerator can accelerate negative ions in a potential of 10 MV. The ions will leave the accelerator as positive ones. The other is a linear accelerator and is used as a booster.

The major research is done in studying the high spin states of various atoms. By shooting a little ion into a bigger one, the fused ion will begin to turn and cast out a rotating particle.

An example of such a reaction is:

\[ ^{40}\text{Ca} + ^{92}\text{Mo} \rightarrow ^{132}\text{Sm} \rightarrow ^{126}\text{Ce} + \alpha + 2\, p + \gamma's \]

By detecting the gammas, one can calculate the spin states and the form of the nucleus; whether it is prolate or oblate.
The detector is called Nord Ball. It looks like a soccer-ball, constructed with 20 hexagons and 12 pentagons. The nuclear reaction will take place in the middle of the ball. The inner side of the ball has a silicon shield for detecting heavy ions. The BGO-scintillators fits in the pentagons and the hexagons.

The same techniques are used by the atom-research group. By making sodium-clusters, it seems that there is a preference for the number of atoms in the cluster. The nuclear magic numbers appear in the number of sodium atoms. The idea is that the wave functions of the electrons do determine the number of atoms. A cluster can contain more than 2000 atoms.

Quantum chaos is studied by looking at wave-functions in microwave cavities with shapes where classical orbits would be chaotic. Then the distribution looks like chaos. But it can be seen as a combination of various quantum wave functions in a structure. By making the cavity superconducting more than 1000 states can be resolved. An important mathematical difference is that in such processes the Poisson distribution will change into a Wigner distribution.

The speaker himself is doing his experiments in the Saturn laboratory near Paris. He is looking at (p,n)-like reactions, e.g. \( ^{3}\text{He},\gamma \) in nuclei, by bombardment with 1 GeV/A \(^{3}\text{He} \). The detection takes place by the time-of-flight method.

There are two mechanisms for (p,n) reactions. The first turns an electron into an anti neutrino and uses a W\(^{+} \). The second turns an other proton in a neutron using a positively charged pion.

There are three energy regions to look at. The first is around \( E_{\text{ex}}=10 \text{ MeV} \). It tells something about the structure of the nucleus. The region around 50 MeV tells something about the quasi free behaviour. Finally the region around 300 MeV is called de \( \Delta \) -region. Here the following reactions are studied:

\[
\begin{align*}
\text{N}(1/2,1/2) & \rightarrow \Delta(3/2,3/2) \\
p & \rightarrow \Delta^{++} \quad \text{(uud \rightarrow uuu)}
\end{align*}
\]

By measuring the energies of the \( \Delta \)'s it seems that \( E(\Delta_{\text{free}}) \) is not equal to \( E(\Delta_{\text{nu-}} \text{cleus}) \). Now they are searching why it is different.
Niels Bohr Archive

The Niels Bohr Institute accommodate the Niels Bohr Archive. It maintains all publications of Niels Bohr, including the collected works. All 6000 letters and 1000 manuscripts are catalogued in a card-system, and are now being put into the computer. The manuscripts themselves are kept in acid free folders and acid free boxes, and placed in fire free lockers.

We have also seen the famous letter Niels Bohr has written to Rutherford about the atom model.

Fig. 1: The letter from Niels Bohr to Rutherford
Scandinavia study tour

It is remarkable that in a lot of letters, scientists have mentioned the good atmosphere during their stay in the Niels Bohr Institute. That is how Niels Bohr could get a lot of brilliant scientists to Denmark.

**Bernhard Pagel, Astrophysics**

In Denmark astrophysics is done at NBI, Nordita, NBI f APG and DSRI (Danish Space Research Institute). Research topics in astrophysics are:

1) the Big Bang: cosmic microwave background radiation, formation of large scale structure, nature and amount of dark matter
2) formation and evolution of galaxies
3) stellar evolution and nucleosynthesis: age of galaxies and universe, supernovae, origin of chemical elements
4) relativistic astrophysics: neutron stars, black holes, quasars, gravitational lenses (galaxy clusters).

Evidence for the Big Bang is given by the fact that our universe is expanding (Hubble expansion) and by cosmic microwave background radiation. The size of the universe can be described by Friedman-models in which a parameter $\Omega_0$ can be chosen. This parameter is proportional to the total mass of the universe. In these models the size of the universe is zero at $t=0$. For $\Omega_0 < 1$ the universe is always expanding. For $\Omega_0 = 1$ the expansion of the universe is stopped after infinite time. This Einstein-De Sitter model is barely closed. For $\Omega_0 > 1$ the universe is closed or oscillating.

After the thermal history of the universe had been discussed, a demonstration was given of some modeling that is done at NBI. In the model that was shown certain conditions at $t=0$ were assumed and the formation of galaxies was calculated taking the existence of dark matter into account. Spiral arms of galaxies were produced in another model.

**Jørgen Dines Hansen, Experimental High Energy Physics**

For getting information about particles a certain temperature is necessary:
The experiments at CERN are concerned with an e⁺e⁻ reaction. It produces a Z⁰. The particles formed in the reaction in the LEP storage ring are detected by several detectors. Around the reaction region, three cylinders are placed. The inner detector detects the particles. The detector in the middle detects momentum and the charge of the particle and the outer detector the energy.

The result was that the Z⁰ has an energy of (91 ± 4) GeV. The deviation is caused by the Heisenberg principle: The uncertainty in the energy times the uncertainty in the time is equal or less than half of the constant of Planck.
New development at CERN

A new ring will be placed on top of the LEP: the LHC. It will get 10 T superconducting magnets and a double beam system (like the LEP). It will produce 7 TeV protons. It will be used for searching the top quark, the Higgs boson (spin 0 particle) and the Z'.

ATLAS is used for detecting muons and doing EM and hadron-calory measurements. The big problem with the muon detection is that the data rate is about $10^9$ Hz, but the useful event rate will be about $10^{-4}$ Hz.

Holger Bech Nielsen, Theoretical High Energy Physics

The standard model (Glashow 1961, Weinberg 1967 and Salam 1968) works perfect up to limitations in testing it. It contains 12 Gauge particles of spin 1. Those are the photon, the weak bosons $W^+$, $W^-$ and $Z^0$, and eight gluons. Further it contains particles of spin 1/2 of which the quarks appear in three different colours. Those are the first generation quarks up and down, the first generation leptons elektron with associated neutrino, the second generation quarks charm and strange, the second generation leptons muon with associated neutrino, the third generation quarks top and bottom and the third generation leptons tau with associated neutrino. Then there is a spin 2 particle called graviton which has never been seen and produces gravity. Finally there is a spin 0 Higgs boson which also has never been seen. All particles of the standard model get their masses by reacting with the Higgs field. If the Higgs particle will not be found, probably another particle will be found that would do the job.

With this standard model we have a theory that with very little parameters can explain everything that we can measure today within the accuracy that can be achieved. So there is much belief in the standard model as a good model, also the concept of gravity is believable, whereas quantum gravity is just an idea. There is only very little information on laws of nature left to tell theorists which model beyond the standard model is right.

If $\hbar$ and $c$ are set to 1, inverse masses can be expressed in units of length. For the $Z^0$ holds that $1/M_{Z^0} \approx 10^{-17}$-$10^{-18}$ m. It is impossible to locate positions with more precision than the Planck length $1/M_{Pl}=G^{1/2} \approx 10^{-35}$ m (G is the gravitational constant). If $Z^0$ corresponds to a fly, the Planck energy corresponds to a heavy loaded train at full speed.
In the standard model all particles are seen as point shaped. In the superstring theory on the other hand particles are seen as line shaped, whether open or closed. These strings have a typical size of $10^{-35}$ m.

A weak point of this theory is that there are too many superstring theorists on the market, a good point however is that the theory is promising to do the job of unification of forces.

The space of supersymmetric (SUSY) strings has nine spatial dimensions and one time dimension. Mathematically this space can be expressed as $E_8 \times E_8$, in which $E_8$ is a group of transformations that contains the group SU(5). To return to the standard model one first has to get rid of some of the $E_8$ particles and then keep 12 of the 24 spin 1 Gauge particles of SU(5).

For unification the strengths of the electromagnetic, weak and strong interaction have to meet each other at a certain energy. The groups corresponding to this interactions are respectively $U(1)$, $SU(2)$ and $SU(3)$. $SU(2)$ because of two allowed states of isospin and $SU(3)$ because of the three colours quarks can have. A measure for the strength of an interaction is the fine structure constant $\alpha_i$. $SU(5)$ with supersymmetry predicts that a fit is possible in which the crossing is perfect as illustrated in Fig.3.

Supersymmetric particles should exist, but there is still no experimental evidence for them. The scale at which the lines cross is just the scale where we are now. The answer whether supersymmetric particles exist is just around the corner. We are close to a theory of everything, but probably all of them are wrong.

**Acknowledgements**

Thank you very much for the fantastic visit.
Introduction

We were welcomed by Hans H. Andersen, who made a general introduction to The Niels Bohr Institute and The Ørsted Laboratory.

Since January 1993 The Niels Bohr Institute is the name for several institutions. These are the former Niels Bohr Institute, Tandem, Astronomy, Geophysics and Ørsted Laboratory. In the former Niels Bohr Institute one makes researches into the fields of theoretical and experimental particle physics, theoretical astrophysics, nuclear physics and nonlinear phenomena. At Tandem they are working in the field of experimental nuclear physics and experimental cluster physics. Astronomy consists of two buildings. One is Østervold where one studies mainly theoretical astrophysics, for observations are not possible there because of the weather. The second is Brorfelde which is an observational facility. At Geophysics, glaciology and experimental and theoretical climate research is done together with oceanography and geodesics.

But today we are visiting The Ørsted Laboratory. Here about fifty scientists, including Ph.D. students and visitors are making researches into the fields of condensed matter physics and atomic physics. In the same building as The Ørsted Laboratory are also situated the faculties of physics, mathematics, computer science and chemistry of the university of Copenhagen. So there are many students doing practical work at Ørsted Laboratory.

To the facilities of The Ørsted Laboratory belong implantation accelerators, x-ray facilities, a Philips transmission electron microscope, analysis equipment and facilities for low temperatures.

Lasers and Atomic Collision Physics

After the introduction Jan Thomson told us something about a collision experiment, they are building up. The goal of that experiment will be to look at the mechanism of ions hit by a laser and an excited atom.
The formula which describes the experiment is:

\[ X^+ + Na(3s, 3p) \rightarrow X(nl) + Na^+ \]

Here the \( X^+ \) can be \( H^+, He^+, Li^+ \) or \( He^{++} \) of 5-10 keV. The \( X(nl) \) atoms will be detected and the \( Na^+ \) ions will be bend away. The experimental setup is drawn schematically in figure 1.

![Diagram](image)

**Fig. 1:** A schematic picture of the experiment.

The frequency of the incoming laser will be determined as follows: The laser that will be used for the experiment is pumped up by an Argon pump laser. After the light has gone through a number of lenses and mirrors the laserlight is polarized vertically. This vertically polarized light as well as the light of a Helium laser, of which the frequency is exactly known, is sent into a frequency-meter. In the frequency-meter the light of the Helium-laser interferes with the vertically polarized beam. From the interference patron, one can get the frequency of the used laserlight.

There only takes place a reaction between the Na-atoms and the \( X^+ \)-ions, when the orbitals of the \( X^+ \)-ions are directed parallel to the E-field of the laserlight (vertical). So the cross-section is dependent of as well the E-field as the direction of the orbitals.
Because the experiment is very sensitive to magnetic fields, we have to compensate for them. The magnetic field of the earth is compensated by coils, which are placed around that part of the experimental set up, where the $X^+$ ions, the Na atoms and the laserlight interact. Because of the fact that the experiment is still being build up, there are no results yet.

**Ion Implantation of Nanocrystals**

After the lunch Erik Johnson and Allan Johansen told us about ion implantation and the research they are doing on the nanocrystal which are related to this experiments.

When you put two metals together, two states can occur. The two metals can diffuse and after cooling you get a alloy. But you also can get two separated parts after the cooling. Several methods exist to avoid the latter state. One is to cool the two metals down very quickly (about $-10^6$K/s), another one is ion implantation. This works as follows: one of the two metals is implanted atom by atom, i.e. the second metal is literally shot into the other.

The real goal of the experiments is not yet in question. The group is more analyzing the metals which are made by the implantation. They are using the following two methods: channelling analyze and TEM (Transmission Electron Microscope). The channelling analysis works as follows, one shoots He$^+$ on the metals and these ions are reflected. They have lost energy depending on which atom they have hit. If one measures this energy and compares it with their original energy, one can say which atom they have hit. Depending of the number of counts one can say something of the number of the two atoms in the metal. The problem of this method is that you need two atoms with a different mass. The TEM is more or less used to make a 'picture' of the metal and one can use it to compare with the first method. The metals which are used to implant are $^{27}$Al...$^{64}$Cu and they are implanted into $^{205}$Te, $^{208}$Pb, $^{209}$Bi.

Here are some results of the analysis. As expected the ion which is implanted is penetrating into the other metal just for 100-200 nm. If you make a diagram of the implanted ion as a function of the penetration depth you get the picture shown in figure 2. You also can see that the implanted ion is better spread in the metal if the temperature is higher, but it is still not homogeneous.
Another problem which is found is that one shouldn’t implant too many ions, because then they the implanted ion will ‘feel’ each other and form clusters in the other metal. This could be solved when one uses a lighter metal to implant but then one couldn’t detect this metal with the channelling analysis.

Something else which is being analyzed whether the orientation of crystal influences the results of the implantation. The result is shown in figure 3. One can see that the number of implanted ion is higher when the crystal-layers are not placed parallel to the incoming ion-beam. There are also some results of the analysis of the clusters. One has done some research on the size of the clusters. There are some metals e.g. Te(110) in which the cluster-size is becoming smaller when the implantation temperature is rising and in some cases the cluster will melt.

At last they showed us the fast cooling system, see figure 4. The metals are sprayed in a copper ring which is spinning very fast. This is happening in vacuum. After that a needle is put on the ring so the alloy is scraped of the ring and this strip is send into a long tube in which it’s expanded and in this way it’s cooled down very fast.

So these are the to ways in which this group is making and analyzing alloys and trying to find answers to the problems we mentioned above.
MBE and Low Dimension Physics

At the Ørsted they also have a group which is doing research on low dimensional electron gas, namely a 2-dimensional gas. The samples which are used for these experiments are made with the MBE (Molecular Beam Epitaxy). This MBE is run by Claus B. Sørensen. First he explained how the MBE-machine works, a scheme of the machine is show in figure 5. The solid source materials, which are to be grown on a substrate (GaAs), are heated. Shutters then will open and close according to the need there is of a specific material. The materials will then grow on the substrate, while this is rotating. Of course one wants to know how the material are grown e.g. how many monolayers are grown. To analyze this one sends an electron-beam under a small angle onto the sample, during the growth-process. Because of the Bragg-conditions one sees a diffraction-pattern. If one then blows up one of the black lines of this pattern one sees an oscillation shown in figure 6. Between two peaks shown in this figure one monolayer is grown. This is unfortunately the only thing, which is to be seen from the diffraction pattern. There isn’t an explanation for the whole pattern at this moment.
After this Sørensen told us which structure he is growing for the research on the 2-dim electrongas. A section of the structure is shown in figure 7.

Now we knew which sample is used for the research Konstantin Baklanov was going to tell something of the research on the structure. First he showed us the sample shown in figure 8.

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**Fig. 5:** A scheme of the MBE-machine. The system is in vacuum.

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**Fig. 6:** The intensity distribution of one line of the diffraction-pattern.

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**Fig. 7:** The structure of the sample which is grown here with the MBE.
Some golden contacts are put on the structure. One of the small gaps between the golden contacts is blown up and also shown in figure 8. When one puts a voltage on contacts one creates a barrier (dotted line) whose width depends on the voltage. Now it’s possible to transport one single electron through this barrier.

The mechanism can be explained as follows: an electron can be seen as an electromagnetic wave. So one can see the transport through the barrier as a wave which reflects on the walls, like a normal light-beam. Because these experiments are all done in the ballistic regime, there is no deflection. Depending on the width, thus the voltage, there are different modes of the wave which can be transported through the barrier just like normal light. After some calculation one can find an equation for the conductivity,

$$G = \frac{e^2}{h}$$

When one measures the conductivity of the electrons as a function of the voltage, one gets a diagram as shown in figure 9.

One can see that the conductivity is being quantized. Each step in the diagram means that the following mode can be transported through the barrier (the first step means the 0$^\text{th}$ and 1$^\text{st}$ mode). With this experiment in mind K. Baklanov is measuring on the Quantum Hall Effect. One uses a sample as shown in figure 10.

When one measures the magneto-resistance one can look at the electron transports through channels along the edge of the sample, which are drawn in figure 9, in the same way as the transport through the barrier in the first experiment. Each step in
the resistance which occur at the Quantum Hall-effect, means a new channel along the edge. So K. Baklanov uses these and other experiments to find an answer to the mechanism of the Quantum Hall Effect as it occurs in a 2-dimensional gas.

**Fig. 9:** The conductivity as a function of the voltage put on the contacts.

**Fig. 10:** The sample used for magneto-resistance and quantum Hall-effect.

**Acknowledgements**

After a very interesting day at the H.C. Ørsted Laboratory we thanked prof. H.H. Andersen and all the persons who contributed to this visit.
Copenhagen

In 1043 the first report was made of a small fisherman’s village called "Havn". During the years a lot of merchands settled in the village. This is why the name changed to "Köbmanshavn" and later to Copenhagen. In 1416 Copenhagen became the capital of Denmark.

During our cultural day in Copenhagen we paid visits to several musea, the Royal Theatre, the botanical gardens, a lot of ancient buildings and other sights of the city.

Ny Carlsberg Glyptotek

The Glyptotek is famous for its outstanding collection of statues from the antique period. There are statues from ancient Egypt, Greece and the Roman Empire. The museum also has some very nice sarcofags, and a great deal of paintings from the renaissance. The Glyptotek, see figure 1, was founded by Ny Carlsberg, and is still property of the Carlsberg foundation.

Fig. 1: The Glyptotek
The National Museum

The National Museum has a very large ethnographic exhibition from all over the world. Of course the museum contains a rather large amount of Danish art from the prehistoric times till the present and also the Royal Collection of Coins and Medals.

The Royal Palace

At twelve o’clock in the afternoon one can see the changing of the guard at the Royal Palace called Amalienborg. This only happens when the queen is in her residence. The palace consists of four buildings in Rococo-style, built around a square. The palace was built in the middle of the 18th century, to accommodate for four nobel families. In the middle of the square there is a statue of Frederik V.

The Royal Library

The Royal Library, which was established in 1653, includes over 2.5 million volumes, 4 million maps and over 55,000 manuscripts. Being the Danish national library it has a complete collection of Danish prints, the oldest from 1482, besides manuscripts by Hans Christian Andersen and Soren Kierkegaard.

The Round Tower

The round tower was built on the initiative of King Christian IV (1588-1648) with Hans Steenwinkel the Younger as architect. The tower was to gather three important facilities for the scholars of the 17th century: an astronomical observatory, a students’ church and a library. The 209 m long spiral ramp winds 7.5 turns round the hollow core of the tower, forming the only connection between the individual parts of the building complex. The round tower is the oldest functioning observatory in Europe. Until 1861 it was used by the University of Copenhagen, but today anyone can observe the night sky through the fine astronomical telescope of the tower in the winter period.
The botanical gardens

25 Acres of landscape garden (laid out in 1874) with rare trees, shrubs and herbs from all over the world. There are Danish plants, rhododendrons, old rose varieties, mountain, aromatic and aquatic plants. In the Large Palm House you can find tropical and subtropical plants and in the several greenhouses there are collections of cactuses, begonias, orchids and carnivorous plants.

The little mermaid

At the point of the harbour there is a small bronze statue of the little mermaid. It is inspired by a fairy-tale from Hans Christian Andersen.

The city hall

The city hall was built in the period between 1892 and 1905. The tower of the city hall is 106 m high. On the top of the front door there is a statue of bishop Absalon (1128-1201), the founder of Copenhagen. In the city hall there is a clock, which gives the time of all the important places in the world and also some astronomical information.

Tivoli

In the evening we visited the famous (attraction) park Tivoli. It is said to be a fairytale garden, with a lot of amusements, restaurants, lamps, concerts and artist shows. At the end of the evening we could watch the famous fireworks, because of Tivoli’s 150th anniversary.

The Royal Theatre

September the 16th we visited the opera "King and Constabel" (Drot og Marsk) from Peter Heise.
The Carlsberg Brewery has the possibility for visiting the plant. For entering the brewery there are several security rules. The most important rule is that it is forbidden to take along foreign beers, such as Heineken. Then there would be a possibility that the fermentation process can be disturbed. The other possibility is that other visitors could change their minds. So they have installed a special device to carry off this beer.

The guided tour begins with explaining the (old) logo of Carlsberg. It is a swastika surrounded with a twelve pointed star. After the Second World War they have changed the logo on the bottles, but they have not removed it from the buildings. The swastika is a 4000 year old Indian symbol standing for youth and strength. The logo was thought of by Carlsberg himself in 1853 after two of his children has died. It had to give strength for his other two children.

The process of making beer is complex. It starts with Danish barley. After it is steeped in water and it is germinated into green malt, it can be dried. This malt is crushed and mixed with water. Now, it can be heated and mixed with hops. After cooling it is stored for 1 month. Now the beer is ready. After centrifugating, it is put into the bottles.

In the cellar all kinds of bottles are stored. They are been placed in the Guinness (!) book of records for having the most different kinds of bottles. The Carlsberg brewery also owns the Carlsberg house. One person who has done praiseworthy things, can live his whole life in this house. It has been said that the person may drink as much as beer as he likes. Also Niels Bohr has lived there from 1932 to 1962.

The old factory has not been pulled down, but is used for schools. Students have to indicate the difference between old and new production methods.

Afterwards there was the possibility for tasting the beers. There were three kinds of beers present. The normal Carlsberg pilsner (4.5 % V/V), the 'gold beer' (5.5 % V/V) and an brown beer (4.5 % V/V). We had to admit that all beers tasted good.
Introduction

The Royal Institute of Technology or 'Kungliga Tekniska Högskolan' (KTH) is founded in 1827. It is the largest institute for engineering education and technical research in Sweden, having about one third of the total capacity of the Swedish university system in these areas. It has about 7000 students, 1000 postgraduate students and 2500 employees. The KTH has extensive international contacts because they consider it very important to function as an integrated part of Europe.

The KTH is a research-intensive institute. Its teaching and research activities cover a broad spectrum, from natural science to all branches of technology, as well as architecture, industrial economics, urban planning, labour science and environmental technology. We looked at several fields of research in the field of physics.

Theoretical Physics

To calculate the several states in, for example, a bcc-lattice is rather difficult. Nowadays one can calculate them with a computer. The ground state is interesting, because the energy of it determines the stability. It was found that a crystal made of C and N should be a very hard material, even likely to be harder than diamond. The problem is, that all C-N compounds made are amorphous. Other interesting states being explored are non-stable states.

Another field being researched is the thermal conductivity of cast-iron. Cast iron has inclusions of graphite, which limit the mean free path of phonons, and thus limiting the thermal conductivity of cast-iron. They are looking for effects due to (an-)isotropy and different structures and compounds.
Optical physics

'Smart' materials

How is it possible to measure the strain in a material, for example in a wing of an aeroplane? A solution is to attach a fibre, with (optical) properties depending on the expansion, to the wing. The fibre becomes sensitive to expansion when you make a Fabry-Perot out of it by putting gratings in the fibre. A problem is that the fibre is also sensitive to temperature. To compensate this you have to know the temperature. So why don't you measure it with another fibre, with another temperature-and strain-dependence! Dual fibers are made with two cores, which act as independent waveguides, and which have those different characteristics.

Fig. 1: An (experimental) fibre-optic sensor system for simultaneous measurement of strain and temperature.
About directional couplers and signal-amplification

You can split the signal in a fibre by moving another one in the immediate neighbourhood of it. Then you get frustrated total internal refraction in the first one. By introducing asymmetries or gratings in the materials you can force the light to go only in one of the fibers. The issue is to get the intensity ratios as good as possible. The schematic set-up of such a directional coupler is given in the following figure.

![Fig. 2: A directional coupler](image)

By injecting pumping-laserlight with such a coupler in a fibre transporting a communication-signal, the signal is amplified if a little further the core is made of 'laser-material' in which rare-earth active dopants are applied. It works by exciting the electrons from the ground state to a second excited state. When these electrons fall to the first excited state, inversion (when higher energy-levels are more occupied than lower ones) between the ground state and this first excited state can be achieved. The energy-gap between the ground-states and this excited state must be the same as the energy of the 'signal'-photons. In this way one achieves that stimulated emission is more frequent than absorption, and thus achieving signal-amplification.

3-dimensional images

The idea of getting 3d-images on your computerscreen of, for example, the structure of a bone is based on the way you use a normal microscope: you change the focal plane of your lens-system. The object is placed under the object lens and
Scandinavia study tour

is scanned by a laser beam in three dimensions. Only the light that comes from the focal point of the object lens is focused properly on the aperture before the detector.

A possibility to increase the resolution is to illuminate only the spot you look at. The best way to do this is to use the same lens-system. When you don’t want the laserlight in your detector, you make sure that the light you look for (another color that comes from fluorescence) follows another way to the aperture/detector by using a dichroic. The resolution of the apparatus is about $1 \mu m$ and the scanned volume is about $(250 \mu m)^3$. When all data is transferred to the computer, you can look at a beautifully rotating bone.

2-dimensional Fourier-transform

To increase the understanding of the Fourier-transform a computer-program can visualize the transformation in two dimensions, from $x$ to $\vec{x}$, changing something in the image, and back to $x$.

![Some scanning microscopes](image)
Scanning tunneling microscopy

Normally an electron in a conductor doesn't have enough energy to 'walk' into an insulator, like the open air. When very close to the conductor another conductor is situated the electron has, according to quantum mechanics, a finite chance to go through the insulator. This chance is exponentially decreasing with the distance between the conductors. When a voltage is applied between the conductors the chance differs with the direction of movement, so a current can be measured, the (quantum-) tunneling. If one of the conductors is the specimen to measure and the other is a very sharp tip (R ≈ 2 Å) you can estimate the distance. When you move the tip around by using piezo-electrical crystals, you can scan the surface. Normally the current is held constant, by letting it steer the 'z'-direction, normal to the specimen-surface, thus avoiding the tip touching the specimen. Using this technique you can even resolve individual atoms (when conducting)!

Measuring laser pulses with an autocorrelator

How to measure the intensity of a laser pulse of a few picoseconds length as a function of time? With an autocorrelator! When you split the laserbeam into two beams, of which one beam is made longer, and let them both fall on a nonlinear crystal in the configuration shown below, you get a signal \((1 + 2)\) with doubled frequency only if the pulses of beam 1 and beam 2 fall on the crystal simultaneously. When you delay the two beams relative to each other, and continuously scan over the delay time, you can produce the autocorrelation function of the pulse and display it on e.g. an oscilloscope. This gives an estimate of the pulse shape, sufficient for laser aligning purposes.

![Fig. 4: Frequency doubling by combining photons in a nonlinear crystal in three ways.](image)
Iris

The Iris is a machine for determining the position of the stars. Special about Iris is that the lens-system doesn't have to be very precise: Iris can work with a blur by determining the position at which the total intensity at one side of the detector is the same as the total intensity at the other side. When the position of the stars are given Iris can determine the precise position of the stars, all automatically.

Material physics: amorphous materials

The department of Condensed Matter Physics (CMP) is studying materials in which the translational periodicity is irrelevant, due to disorder or to the small dimensions of the structures. Some of these materials have very interesting properties:
- they are magnetic extremely soft materials
- in a superconducting state very high critical currents can be reached
- etc . . .

Acknowledgements

We would like to thank prof. N.G. Nilsson and all the persons who have contributed to the visit for the organization and the interesting lectures.
Scandinavia study tour

Alfvén laboratory
September 21, 1993
Rob van Schaijk and Raymond Cuypers

On Tuesday 21 September two excursions were planned. In the morning we visited the Alfvén laboratory, department of fusion physics of the Royal Institute of Technology. In the afternoon a visit to the Manne Siegbahn Institute of Physics, a part of the university of Stockholm and R.I.T., was on the program.

Alfvén Laboratory

The laboratory is named after Hannes Alfvén, one of the foremost space physicians of our time. This laboratory works on the field of nuclear fusion research. They work with fully ionized plasmas, the so-called fusion plasmas. They collaborate with the Joint European Torus (JET) in Culham, the biggest fusion reactor in the world. The fuels which can be used in a plasma reactor are deuterium (D), tritium (T) and lithium (Li). The most suitable fusion reaction is:

\[ D + T \rightarrow ^4\text{He} + n + \text{Energy} \]

This is because of the greater size of the cross section in comparison with other fusion reaction like:

\[ D + D \rightarrow ^3\text{He} + n + \text{Energy} \]
\[ D + D \rightarrow T + p + \text{Energy} \]
\[ D + ^3\text{He} \rightarrow ^4\text{He} + p + \text{Energy} \]

Tritium has to be produced by a tritium breeding reaction from Lithium:

\[ ^6\text{Li} + n \rightarrow T + ^4\text{He} \]
\[ ^7\text{Li} + n \rightarrow T + ^4\text{He} + n \]

A magnetic field can be used to isolate the plasma from the vessel walls. The most promising magnetic confinement system are toroidal (ring-shaped) and the most advanced is the tokamak.

The Tokamak and other confinement concepts

At the Alfvén laboratory an Extrap T1 is used, see figure 1. Extrap T1 is an alternative confinement solution where the confining magnetic field is used more efficiently than in a tokamak and the heating of the plasma to ignition should be possible by ohmic power only. In the extrap T1, plasma is heated in a toroidal
Scandinavia study tour

vacuum vessel and confined away from the vessel walls by magnetic fields. The basic components of the toroidal magnetic confinement system are:
*The toroidal field which is produced by coils surrounding the vacuum vessel (TF coil)
*The poloidal field produced by a current in the plasma. The plasma current is induced by transformer action. (there are two iron transformer cores visible, the plasma ring is the secondary circuit.

![Diagram of Extrap T1](image)

$$R = 0.5 \text{ m}$$
$$R/a = 8.9$$
$$<n_e> = 1 \times 10^{20} \text{ m}^{-3}$$
$$<j_p/n_e> < 1 \times 10^{-13} \text{ Am}$$
$$\gamma_L \cdot \text{shell} = 400 \mu\text{s}$$

Fig. 1: Layout of Extrap T1.

The heating of the plasma in a JET tokamak is done by the following heating methods:
1) Ohmic heating: A current of up to 7 MA is passed through a small quantity of the fuel gas in the toroidal vacuum vessel. This heating is not efficient enough
because at high temperature the resistance of the plasma is so low that further heating by this method has no effect.

2) Neutral beam injection heating: Ionized hydrogen atoms are accelerated by 100 kV voltage to increase their energy and are then neutralised (by passing them through a parent gas). Then they can penetrate the magnetic fields surrounding the plasma. In the plasma the energetic atoms become ionised again and by collision give up their kinetic energy to the plasma.

3) Radio-Frequent Heating: The ions and electrons in the plasma spiral around the magnetic field lines of the tokamak. Energy can be given to the ions if radio waves with similar frequencies are beamed into the plasma.

For fusion the plasma must satisfy two independent conditions, the so called Lawson criterion which involves three parameters.

1) Temperature: Fusion reactions occur at a sufficient rate only at very high temperature. At this temperature the individual particles can overcome the Coulomb repulsion. The critical temperature for a D-T reaction is 7 keV and 40 keV for a D-D reaction.

2) Confinement time: The efficiency of the magnetic insulation is measured by a quantity called the energy confinement time. This is the characteristic time scale for plasma cooling when the source of heat is removed; the confinement time must be sufficiently long.

3) Density of fuel: The density of fuel must be sufficiently large for fusion reaction to take place at the required rate.

The Extrap T1 experiment is a relatively small experiment not designed to fulfil the Lawson criteria for fusion. Also in the new machine, the Extrap T2 with a higher temperature (500 eV) and higher plasma current (300 kA), there won’t be fusion. These experiments are designed for understanding the principle of fusion and plasma behavement. The experiments with new materials are also important for future nuclear fusion reactors. New materials which can stop high energetic neutrons without becoming radio-active.

The experimental program of the Alfven laboratory is:

a) Equilibrium and stability of the plasma

b) Scaling laws: confinement time of energy (τ_E), confinement time of particles (τ_p) and particle pressure related to magnetic pressure (βθ).

c) Impurity behaviour: the fusion fuel is diluted by impurity atoms released from the surrounding material surfaces or the helium waste from the fusion reaction.

d) Density control.

Fusion research requires the accurate measurement of many plasma quantities, such as temperature, density and energy confinement time. Because of the high tempera-
ture all measurements must be made by remote methods. Some of the important diagnostics will be explained.

- Temperature and density are measured with lasers. A laser sends a short pulse of light through the plasma where some of light is scattered by the electrons. Hot electrons move very fast and the wavelength change of the scattered light (doppler effect) reveals the temperature. The total amount of light scattered gives a measure of the plasma density.

- Plasma purity is measured by vacuum ultra violet (v.u.v.) spectroscopy. The spectroscopic diagnostics consist of spectrally resolved measurements in the v.u.v. region from 10 nm to 110 nm for impurity line radiation.

- Shape and position of the plasma is measured by magnetic methods using arrays of magnetic coils.

With the measurement of the dominant ion concentration with spectroscopy, the proton density $n_p$ is known. With the knowledge of $n_p$ and the electron density $n_e$, the total density can be calculated. With the density and temperature the confinement time can be calculated; following formulas are valid for the plasma conditions in Extrap T1, run in reversed pinch mode [Ref.]:

$$\tau_p = \frac{\langle n_p \rangle}{0.42 \Gamma - \frac{d\langle n_p \rangle}{dt}}$$

$$\tau_e = 5.6 \cdot 10^{-21} \frac{\langle n \rangle T}{P(\omega)}$$

$\Gamma =$ hydrogen influx (calculated from Balmer alpha radiation)

$P(\omega) =$ total input power

Acknowledgements

With this formulas ends the report of a visit to the Alven Laboratory. We thank the people who organised this visit: James R. Drake, Jerzy H. Brzozowski, Björn Bonnedier and others we might have forgotten to mention.
Manne Siegbahn Laboratory (MSL)

In the afternoon of September the 21st we visited the Manne Siegbahn Laboratory. The institute is named after Karl Manne Georg Siegbahn (1886-1978). The study of X-ray spectroscopy would win him the Nobel price for physics in 1925. Siegbahn was an eminent experimentalist and designer in the field of nuclear physics. In 1935 the institute in experimental physics was founded with Siegbahn as director of the institute. Since July 1, 1988 the institute, in remembrance of its founder, is called MSL.

The CRYRING (see figure 1) is presently the main research facility of the MSL. The facility is unique for studies of the interactions of very highly charged heavy ions with photons, electrons or other ions. CRYRING is an acronym for CRYsis connected with an acceleration and storage RING.

![Figure 1: Layout of the CRYRING facility.](image-url)
The main parts are:

1) CRYSIS: Cryogenic Stockholm Ion Source. An intense beam of electrons is used to produce highly charged ions of an introduced element. CRYSIS consists of an electron gun producing an electron beam which is compressed and confined by the magnetic field of a superconducting magnet. The beam guide is in ultra high vacuum to prevent recombination of highly charged ions. Ions are trapped in a potential well, created radially by the electron space charge and axially by a system of tube-electrodes around the beam.

![Diagram of CRYSIS](image)

*Fig. 2: The potential distribution in the CRYSIS.*

Figure 2 shows the potential distribution along the beam during ionization. A beam of singly charged ions is injected through the electron collector. (potential distribution g). When the trap is full the distribution is changed (h) and the ions are trapped. The charge state increases gradually by successive ionization as the ions collide with the energetic electrons. After a selected ionization time the potential distribution is changed (j) and the ions are extracted through the electron collector.

2) R.F.Q.: a Radio Frequent Quadrupole used as an accelerator for heavy ions. A high frequency (108.5 MHz) AC signal is connected to the four rods. This gives rise to high electric fields between the rods. The forces between the rods keep the ions together in a narrow beam. Due to the wave-shaped rods, an electric field directed along the rods is also generated which alternates with the radio frequency.
The modulation of the four rods increases gradually allowing an efficient bunching of the ion beam prior to acceleration. The acceleration is a resonance process where the shape of the rods and the radio frequency determine the ion velocity through the RFQ. The transmission efficiency is close to 100%. The energy of the ions is increased from 10 keV/u to 300 keV/u with an energy spread of about 1%.

3) An acceleration and storage RING with an electron cooler: This ring has two functions, first acceleration of the ions and to store them for use in different experiments. The ring shaped ion orbit is generated by bending the ion beam through an angle of 30 degrees in the field of each of the twelve dipole magnets. The ion beam is focussed using quadrupole and sextupole magnets.

*Electron cooling (see page 86): Ions circulating in a storage ring such as CRYRING have slightly different velocities. The velocity variations can be regarded as a thermal motion and the task of the electron cooler is to reduce these variations.

The cooling occurs when the hot ion beam (b) is merged over a distance of 1m (a) with a beam of cold electrons (c) having the same average velocity as the ions, but with less variation. Heat is then transferred from the ions to the electrons. The electron beam is guided by magnetic fields (d). The magnetic fields have only a small influence on the ions due to their much greater inertia. Not so long ago the cooling was improved ten times. This is done by adiabatic broadening of the beam. This lab is the first who has improved the cooling, and with this the measurements, using this method.

One of the projects at MSL is the use of a Penning Ion trap for precision measurements on highly charged ions. The invention of ion traps and the development of
cooling techniques have in recent years made it possible to control and to study systems with relatively few particles. Such systems of a few trapped particles provide an important testing ground for condensation theories. It is also used for precision measurement of masses of charged particles.

The strong and constant magnetic field and a mechanical arrangement of electrodes used for radial confinement in the trap causes the trapped ions to perform a circular...
motion with a characteristic frequency given by $\omega = qB/m$ where $q$ is the charge, $B$ is the magnetic field and $m$ is the mass. As can be seen this frequency is mass dependent.

Fig. 6: Oscillations in the Penning ion trap.

Thus using this technique it is possible to accurately measure relative masses by determining resonance frequencies. Two detection methods are applied, one is a measurement of the time-of-flight of the extracted ions, which are compared with time-of-flight of known ions. The other detects image charge currents which are Fourier transformed.

Other projects at MSL, which I will not explain here are:
- Photofragmentation spectroscopy: this is to study how molecular ions are influenced by irradiation with intense laser light.
- Translational energy spectroscopy: This project uses this to study how highly charged ions capture electrons from neutral gas atoms.
- X-ray spectroscopy: This project determines the reactions of highly charged ions in a gas of electrons. In some recombination events X-ray are emitted and detected.
Scandinavia study tour

An electron cooler

Acknowledgements

We thank the people who organised this visit: Per Carlson and others we might have forgotten.
Stockholm

Stockholm, the city built on water, is also known as the "Venice of the North". The city was founded in 1252 by count Birger Jarl. In 1634 Stockholm became the capital of Sweden. During our cultural day we were able to pay visits to the Vase Museum, the National Museum, and on three different nights the opera (20th September), a classical concert (22nd September) and the ballet (25 September).

The Vasa Museum

In the Vasa Museum the original battleship "Vasa" is exhibited. The ship sunk in 1628, just a few minutes after it's contact with the water, because it was not well constructed. Because of the lack of wood-eating animals in the Nordic water the Vasa was contained very well. This way people were able to dig an almost complete ship out of the mud in 1951. After that the ship was treated with a conserving fluid for 18 years, so that now everybody can see the 62 meters long, 12 meters wide and at the stern 20 meters high "Vasa" in it's full glory.

The National Museum

In the afternoon we went to see the paintings in the National Museum. The museum has three departments:

- the department of paintings and sculpture with 12,500 items,
- the department applied art with 30,000 exhibits from the medieval period to the present,
- the department of prints and drawings, which has one of the world's foremost collections of drawings, comprising about 50,000 items.

The museum also has a unique collection of 17th century Dutch paintings (even 7 Rembrandt's) and 18th century French paintings.
The Konserthuset

In the evening we paid a visit to the Konserthuset, where we could enjoy the art of cello-music performed by the winner of the biannal Nordic Solist Competition: Troels Svane Hermansen. The orchestra was directed by Andrew Litton.

The Operan: Tosca

On monday September 20 we visited the Operan to see Giacommo Puccini’s opera "Tosca".

The ballet Törnarosa

On saturday 25th September we visited the Operan for the second time. This time to see the beautiful ballet called "Törnarosa" (i.e. the sleeping beauty) of Pjotr Iljitsj Tsjaikovsky.

Greetings from Stockholm
Introduction

During our visit to the The(odor) Svedberg Laboratory, TSL, Anders Ringbom, a PhD student was our host. After a brief introduction by Leif Nilsson, director of TSL, we visited all facilities of TSL.

Theodor Svedberg was professor in physical chemistry from 1912 to 1949 and was awarded the Nobel Prize for chemistry in 1926. Towards the end of the thirties he and his colleagues constructed their first accelerator, a neutron generator. Nowadays TSL has three facilities: the Gustaf Werner cyclotron, the CELSIUS ring and a Tandem Accelerator. TSL is under national direction and is open to researchers from Sweden and from abroad. Proposals for experimental work are evaluated by a Programme Advisory Committee for they may be conducted. Over fifty research projects are in progress involving approximately 200 scientists.

Gustaf Werner cyclotron

We visited the Gustaf Werner cyclotron and its research projects. This synchrocyclotron accelerates protons and α-particles to a kinetic energy of 240 MeV with a modulating frequency. An ion-source produces small ions which are injected in the centre of the cyclotron with a spiral inflector. The ions are accelerated by two RF-systems, which are placed opposite to each other. A big magnet bends the ions axially to the centre of the cyclotron in circular courses. An electrostatic deflector in the outermost course bends the ions out of the cyclotron.

The produced ion beams are used for different aims. At first there is a well shielded area, called the Crypt, where radio-nuclide such as $^{76}\text{Br}$ and $^{110}\text{In}$ are produced for medical purpose and for nuclear solid state spectroscopy. In the so-called Marble Hall beams of $10^6$ monoenergetic neutrons per second are produced by the $^7\text{Li}(p,n)^7\text{Be}$ reaction. Protons from the cyclotron impinge on a neutron production target ($^7\text{Li}$) and after the target the proton beam is bent into a well shielded beam dump, while a neutron beam can be used. To improve the proton count rate, a sandwiched multi-target system was constructed. It consists of a stack of thin (n,p) target layers interspaced by multi-wire proportional chambers, MWPC.
In this way it is possible to determine in which layer the reaction occurred, and corrections for the energy loss in the subsequent targets can be applied. These neutron beams are used in the so-called Blue Hall to study isovector multipole resonances with a magnetic spectrometer. A compact pair spectrometer called PACMAN, used for studies of particular \((p,\gamma)\) reactions on light nuclei, is also situated in this hall. The experimental set up consists of a pair spectrometer and its detector system, and a monitoring system including two threefold scintillation telescopes looking at the target and two ion chambers placed in the beam behind the scattering chamber. A schematic picture of PACMAN and its detector system is shown in figure 1.
The principle of measuring the energy of $\gamma$-particles by PACMAN is as follows: the $\gamma$-beam is directed to a foil in which an electron-positron pair is created with the same energy as the $\gamma$-particles. The energy of this pair is detected by bending the electron and positron in a magnetic field and detecting them by a line of detectors. In this way the radius of the bending courses is determined, which yield the energy of the electrons and positrons. The third experiment in the Blue Hall is LISA. LISA is a neutron detector, which detects neutrons by converting the neutrons into protons on a Li-foil. Next the beam of the synchrocyclotron is used to fill the CELSIUS ring, which is a storage ring for protons.

**CELSIUS Ring**

Ions from the cyclotron can be injected, stored, cooled and accelerated in the CELSIUS ring, shown in figure 2. It is primarily intended for nuclear and particle physics experiments with ion beams interacting with extremely thin internal targets. CELSIUS can be operated in a static mode or in cycles. In the static mode all machine parameters have constant values and the energy of the stored beam remains at the value at injection. During operation in the cyclic mode the beam may be accelerated or decelerated.

The ring consists of four 90° arcs and four straight sections. The straight sections are used for injection into the ring, beam diagnostics (presently the WASA detector is placed there), electron cooling and for the internal cluster-jet target station with its scattering chamber.

The four quadrants of the ring contain ten dipole magnets and two quadrupole magnets. The dipole magnets bend the ions in the curves, and the quadrupole magnets focus the ion-beam. To fill the storage ring a "long" beam pulse of the synchrocyclotron is sent and injected just above the actual beam. A septum magnet and a electrostatic deflector control angular adjustments, while two time-dependent bending "bumper" magnets bend the beam in the vertical direction. In this way the injected beam is spiraled into the ring. A stripper foil converts the incident ions into the right ions by changing charge.

To create a homogeneous ion-beam an electron cooler is used. Because of the large mass difference between protons and electrons ($m_p \approx 1862m_e$) it is possible to bend an electron-beam into the ion-beam without affecting the ion-beam. In an electron cooler an ion-beam is subjected to friction from an intense electron-beam. This makes the ions slow down or speed up until the speed of electrons and ions has become the same. In this way the energy spread of the ion-beam is strongly improved.
Scandinavia study tour

To be able to store the ions for a long time the ions travel through vacuum of $10^{-9}$ Pascal and have a revolution time of a few minutes. To be able to do experiments at higher energies the electron-cooled ion-beam can also be accelerated in the CELSIUS ring. In a radiofrequency cavity an oscillating electrostatic field accelerates ions with their revolution frequency. With the same frequency the dipole magnets and the quadrupole magnets are increased to keep the ions in their course.

Figure 2: Layout of the CELSIUS ring.

Behind all the equipment the real experiment will be done in the internal target station. The internal targets must be very thin in order not to destroy the circulating beam, thick enough to give high reaction rates. Cluster-Jet Targets, with target beams of gases like deuterium and nitrogen, and fibre targets, mainly made of carbon, are used.
Scandinavia study tour

WASA-project

At the moment the only experiment in the CELSIUS Ring, built in the diagnostics section, is the WASA (Wide Angle Shower Apparatus) project. The elementary particle physics program of the WASA collaboration is intended for detailed decay studies of light mesons to determine the branching ratios of rare decay modes. The detector system WASA contains a pellet-target system, a detector for wide-angle radiation, and a forward detector for particles scattered at angles below 20 degrees (see figure 3).

A proton beam from the CELSIUS Ring is directed to gas targets to measure meson decays. The radiation is detected by CsI-crystal-detectors. The scintillator-crystal CsI emits photons when absorbing γ-photons. A photomultiplier gains the light-signals and converts it into an electrical signal. These detectors are placed all around the target area to be able to measure the angle of radiation.

In the detector the coordinates for polar angles between 25° and 155° and the energy of photons and charged particles are measured by a scintillator electromagnetic calorimeter.

The forward detector consists of hodoscopes, made out of plastic scintillators.

Biomedical Hall

We also visited the so-called Biomedical Hall, see page 99. Here the synchrotron beam is used to irradiate human beings with little doses of γ-radiation. Chemical research is nowadays able to produce macromolecules which can make connections with only the tumour cells. First the patient is injected with these macromolecules which contain 10B atoms. After a certain period the patient is irradiated with a neutron beam of more than 10μg/g. The activated neutron capture reaction 10B(-n,4He)7Li then produces two strongly cell toxic molecules 4He and 7Li, which kill the tumour cells. This radioactive irradiation treatment is called boron neutron capture therapy (BNCT) and at the moment this therapy is used to treat cancer tumours in the eyes. Another treatment which makes use of the neutron capture reaction is the treatment of effects of brain bleedings. In this treatment the part of the brains with the veins, in which blood has clotted, is eliminated by the neutron capture reactions.
Figure 3: A schematic view of the WASA detector.
Tandem Accelerator

We visited the Tandem-Van de Graaff accelerator (page 100), which accelerates ions to a kinetic energy of 6 MeV. The principle of this accelerator is based on two linear accelerators in a line, which are placed in an ultra high vacuum tank (see figure 4). A linear accelerator accelerates ions by a large electric field. In the first accelerator negatively charged ions are accelerated in a potential difference of 3 MV. After hitting a 10 μm thick carbon foil inside the tank, two or more electrons are stripped from the negatively charged ions. The now positively charged ions are accelerated in a reversed electric field of also 3 MV.

![Diagram of Tandem Accelerator]

**Figure 4: Set up of the Tandem Accelerator.**

The Tandem Accelerator has two operating modes: an AC-mode and a DC-mode. The accelerator produces continuous ion-beam in the DC-mode and pulsed ion-beams in the AC-mode. These ion-beams of 6 MeV are used in experiments in applied nuclear physics and in atomic and molecular research. At the moment scientists are occupied with 5 different projects: electrospray ionization in proteins,
laserdesorption in proteins, laserdesorption in ions, fast ion induced defects in silicon and other semiconductors and determination of age of carbon in archeological objects.

**Electrospray ionization of proteins**

In the electrospray ionization process a solution of proteins in acetic acid is vapoured into an electrostatic cavity. In this cavity the haze of drops is accelerated in a potential of 2.5 kV. A quadrupole magnet splits the protein drops from their coat of (charged) protons. The electrospray ion-source is used to bombard a surface of crystals with proteins. Used crystals are SiO₂, Si, HOPG (=highly oriented pyrolitical graphite) and organic crystals. The bombardment with proteins causes an ejection of electrons, ions and neutral particles out of the surface. By detecting these particles as a function of the beam parameters one can determine the topography of the surface. Also an atomic force microscope is used to scan the surface. A little pin moves along the surface with a constant force on the surface. By detecting the height differences one can determine the topography of the surface. The aim of the electrospray ionization project is producing defined protein cluster collided surfaces on crystals for the laserdesorption project.

**Laserdesorption in proteins and ions**

By directing a laser on a crystal surface covered with protein clusters, laserdesorption of proteins is caused. The frequency of the laser is equal to the resonance frequency of proteins. The so caused resonance tears the molecules apart into little molecules, which are emitted. Two mass spectrometers detect these emitted charged and neutral particles. One can also cause laserdesorption in heavy ions. In a vacuum cavity heavy ions are accelerated by a linear accelerator. An laser, which is colliding with the ion beam causes the effect of laserdesorption.

**Fast ion induced defects in silicon and other semiconductors**

An irradiation facility has been built at one of the beam lines of the Tandem accelerator for modification of materials by high energy ions. Fast ions may be utilized to introduce point defects in semiconductor substrates in a controlled way.
Some of the defects that arise after irradiation are very efficient recombination centres for electrons and holes and also have the thermal properties necessary for technological usage. Since the defects are generated predominantly in a narrow region within the irradiated layer shortly before the ions stopped, the lifetime for charge carriers can be reduced at a depth determined by the energy of the bombarding ions.

The resistivity profiles of the materials are measured by Deep Level Transient Spectroscopy. The knowledge of how to spatially modulate the lifetime by fast ion irradiation will be used in the development of silicon power components, such as thyristors.

Figure 5: $^{14}$C in the food chain.
Determination of age of carbon in archeological objects

In air nitrogen becomes carbon by influence of cosmic radiation,
$$^{14}\text{N} + n \rightarrow p + ^{14}\text{C}.$$ 

By the food chain carbon enters living creatures, as shown in figure 5. When these die, the $^{14}\text{C}$ is not supplied anymore so that the concentration will decrease by the decay of $^{14}\text{C}$:
$$^{14}\text{C} \rightarrow \beta^- + ^{14}\text{N}.$$ 

So the ratio $^{14}\text{C}/^{13}\text{C}$ is proportional to the age of the archeological object. The Tandem accelerator has a separate beam-line in which the mass of $^{12}\text{C}$, $^{13}\text{C}$ and $^{14}\text{C}$ can be determined, as shown in figure 6.

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Figure 6: Tandem accelerator and carbon detection system.
Scandinavia study tour

The $^{12}$C and $^{13}$C are detected by Faraday cups. The $^{14}$C is detected by a time-of-flight $\Delta E-E$ detector telescope and diagnostic elements for the final separation and identification of the ions accelerated. Two separate injectors with Cesium sputter ion sources and $90^\circ$ analyzing magnets have been installed.

At present the limit for the oldest age possible to measure is 50,000 years B.C., with an accuracy of 40 years.

Acknowledgements

After a very interesting day we thanked Mr. A. Ringbom and his colleagues for the very interesting lectures and the guided tour in the Svedberg Laboratory.

Irradiation treatment in the Biomedical Hall
Scandinavia study tour

Tandem - Van de Graaff accelerator
Introduction

We were welcomed by Jonas Modéer, who gave us an introduction to Scanditronix. After that he showed us the workfloor.

Scanditronix was founded in 1965 with the goal of developing accelerator equipment for research and applications in the fields of medicine and physics. Some projects over the years are the ESP and Q3D spectrometers in 1965, the Cyclotron program in 1973, the Positron Emission Tomography camera in 1980, the Electron synchrotron in 1982, the Racetrack Micro-tron in 1984 and Electron Beam processing equipment in 1987.

Today Scanditronix is still an internationally reputed company. The business idea of Scanditronix is to deliver systems to generate, measure or apply ionized radiation. These systems can be divided into two groups: medical instruments and industrial and scientific products. To the first group belong the instruments for dosimetry, dose planning, NM, CT, MR, mammography and TLD. To the second group belong the synchrotrons, electron beam treatment systems, medical accelerators and cyclotrons. The clients of Scanditronix are therefore industry, research institutes and hospitals.

Scanditronix also cooperates with several other companies. These are MIT in Cambridge, Medical Research Council at Hammersmith Hospital in London, Hahn-Meitner Institute in Berlin, Karolinska sjukhuset in Stockholm, Memorial Sloan-Kettering Cancer Center in New-York, University of Michigan in Ann Arbor, Gustav Werner Institute in Uppsala and the Uppsala PET Center.

At Scanditronix itself there are working about hundred employees. So it's not a very large company. But because it has always been Scanditronix' policy to invest in research and development of new products of a very high quality, they are an internationally reputed company.
Racetrack Microtrons

Racetrack microtrons get their name from the shape of the electron orbit. Two 180° dipole magnets direct the beam repeatedly through a linear accelerator. At each passage through the accelerator the electron energy increases by a constant amount, and the track grows wider for each orbit. Beams can in principle be extracted from any of the orbits, giving a series of precisely defined output energies. The 50 MeV model offers beams extractable in discrete steps of 5 MeV.

Racetrack microtrons which produce a high energy beam, are used as injectors for boostersynchrotrons and electron storage rings. Beams with a lower energy are used for cancer treatment.

Cyclotron

At an energy of 10-17 MeV the cyclotron is used to produce PET-isotopes. These isotopes have a short lifetime. For producing isotopes with a longer lifetime 30-40 MeV cyclotron beams are necessary. Cyclotron beams of 50-60 MeV are used for neutron therapy.

The problem with cyclotrons is how to extract the beam. Normal extraction gives an efficiency of 75%. To get 100% extraction, one needs a trick. For getting accelerated protons, one has to accelerate H⁺. These are, at extraction, led through a stripping foil, which converts the H⁺ in a proton and an electron. Because of the magnetic field, the proton will be extracted from the cyclotron and the electron will bend away.

Synchrotron

At the moment Scanditronix is building Max II, which is a synchrotron built for The Max Laboratory in Lund. The different parts come from different companies. Some parts of the dipoles par example come from Eindhoven. Here at Scanditronix, they put all parts together and test them. At the moment they are testing the magnets. As is known the magnetic field in a coil is proportional to the current trough the coil. By putting an alternating current on the coils, you get an alternating magnetic field. This field consists of several sines of different order, which are related to the different poles. By putting a pick-up coil into the magnet one can
Scandinavia study tour

measure the induced current. From this current one can see which poles are most present. These must be quadropoles and sextupoles.

Some parts of Max II are already in Lund, where people of Scanditronix are putting them together. So Scanditronix designs, tests and builds its products.

General Electrics Medical Systems

Introduction

We were welcomed by Stig Lindbäck who gave us an introduction to the PET-system and afterwards a guided tour through the building.

At first the PET-system was produced and sold by Scanditronix, but because of the extent of the project they decided to place this project in a new company General Electrics Medical Systems (GEMS). So now the PET-system is under GEMS’s management and they are selling the system to hospitals or other medical centers.

The PET-system

In the medical world there are several diagnostic modalities, for example X-ray,Computed Tomography (CT), Magnet Resonance Imaging (MRI) and Positron Emission Tomography (PET). The first three of the list are used for making anatomical pictures showing different structural densities. The PET-system measures biochemical activity in the human body and therefore gives information of function (not structure).

We now will explain the principles of the PET-system. As said before PET means positron emission tomography. This name can be explained as follows; a radioactive tracer is put into the patient. This tracer will be spread out through the body by the circulation of the blood. This radioactive tracer is short-lived and will decay in the body. The following process will then occur: \( e^+_{\text{tracer}} + e^-_{\text{body}} \rightarrow 2\gamma \). So a positron of the tracer will give two photons in opposite direction when it reacts with an electron of the body. These two photons can be detected by detectors which are in a circle around the body. The detector will detect all events, but only record coincidents. A coincident takes place when the two photons are detected at 'exactly' the same time (within a few nanoseconds). In this way you can filter out
accidental photons.

As said the detectors are in a circle around the body (shown in picture 1.1) so one can only see a thin slice of the body. When one moves the body through the detector ring one can make a tomographic picture of the body slice by slice.

But how do we get the tomographic pictures with the different colors, which means more or less photons coming from that place? This is caused by the fact that the tracer molecule ‘sticks’ more nearby e.g. cancer cells so there are more photons coming from these cells then from it’s surroundings. Another example is that because the tracer molecule can only react with living tissue, one can see which part of the heart muscle is alive or dead after an infarct.

Preparing of the Tracers

GEMS also produces the systems for making the tracers which are used in the PET-system. In figure 1.2 one can see a global picture of how the tracers are made. Protons are accelerated in a cyclotron, in fact not the protons are accelerated but H\(^+\) are, as it is described above (cyclotron). This beam is aimed at nitrogen gas, and splits the nitrogen in carbon radionuclides and helium nuclides. So in a formula: p \(\rightarrow\) \(^{14}\text{N} \rightarrow ^{11}\text{C}\). This carbon is called a precursor. There are also other precursors which are produced in the following reactions:
The precursors are made in target chambers which are placed at the cyclotron. With the precursor one can make the tracers in the following way: $^{11}\text{CO}_2 \to ^{11}\text{CH}_3\text{I}$ (carbon-methionine) or $^{18}\text{F} \to \text{FDG}$. The last molecule is the tracer which is injected into the patient. The tracers just mentioned are so called $^{11}\text{C}$-Methionine and the FDG (Fluor Dioxide Glucose).

The last one is now made fully automatically by the FDG Microlab of which you can see a picture in figure 1.3.

So after preparing the tracers one injects them into a patient and makes a slice by slice picture of him or her with a resolution of about 3-5 mm which is about twice the mean free path length of a positron in the body. Beside the high resolution there is another advantage of the PET-system. As said before the radioactive parts are short-lived, so one can do more experiments on a patient in one day. Although it is a very expensive system, it is a very useful, efficient and refined system for medical research.
Acknowledgements

After a very interesting morning at Scanditronix / GEMS PET Systems we thanked Mr. J. Modéer and Mr. S. Lindbäck for the interesting visit.
Scandinavia study tour

Värmlands
September 24, 1993

This evening we were welcomed by the Students' Association "Värmlands". After some entertainment we had dinner with some of the students, as you can see in the figure below. Our visit ended with a great disco.

Acknowledgements

We owe thanks to the persons who arranged this social event for us: ir. Melssen, Mrs. S. Välne and others we might have forgotten to mention.
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Introduction

The Swedish Institute of Space Physics employs 120 people, of whom 42 are scientists or graduate students. The headquarters are in Kiruna, where rockets are launched and radar equipment is present. The Uppsala Division was founded in 1952 and is older than the division in Kiruna. At the Uppsala Division there are 32 persons of whom 17 are scientists or graduate students.

The difference between space physics and astronomy is that the first studies the space near us, using in situ measurements. Astronomy only receives signals from outer space.

Fig. 1: Different radar sites
As we know (now), the medium between the planets and stars is not vacuum, but a plasma. Therefore plasmaphysics is important. Also in our atmosphere there is ionisation (ionosphere) caused by UV-sunlight. The solar wind interacts with the magnetic field of the earth. This creates very different and distinct areas in the magnetosphere (e.g. radiation belts).

**Radar experiments**

Because you can’t detect much radiation from this iono- and magnetosphere, you must 'go out there', e.g. by using radiowaves. The plasmafrequency (proportional to particle density) can be determined: reflection of the radiowave occurs when the frequency is equal to the plasmafrequency. By measuring the time delay of the wave you can determine the height. Another method uses very high frequency radiowaves, a factor of 100 above the characteristic frequency. Now the electrons in the plasma oscillate and emit radiation. Because of the very small cross section you need a very large radar installation, such as EISCAT. The signal is not a pure line. From the echo power the electron density can be determined, from the Doppler broadening and shift you get temperature and plasmavelocity. See figure below. The shape of the line is used to determine $T_e/T_i$ (electron/ion temperature).

**Aurora**

In Uppsala research is done on the aurora. An explanation for the beautiful light is that electrons come into the atmosphere and excite atoms. A problem is that the electrons in the solar wind haven’t got enough energy, so they must be accelerated in some (still not completely solved) way. In the aurora green light dominates (557 nm from oxygen). Sometimes red light is visible (670 nm, also oxygen). These lines correspond to forbidden transitions, and are not seen in a discharge. The movements of the aurora are reflections of the motion of the plasma, caused by magnetic fields in the magnetosphere.

**Satellite projects**

Viking, the first Swedish satellite project, designed to study the aurora, contains photographic equipment, measurement of potential, induced magnetic field, etc. Now there are two competing models for the aurora.

1. electrons 'surf' on waves, the Maxwellian distribution is distorted (Landau damping), so there is an exchange of energy between electrons and waves.
Scandinavia study tour

2. in the atmosphere there are small regions with potential drops of about 1 V over 100 m. Thousands of these regions cause the acceleration.

The second Swedish satellite project, Freja, contains an 8 MHz data acquisition-system. This means, with a velocity of 7 km/s, a spatial resolution of 1 mm! Now you keep all the information, including phase information. In earlier days a Fourier transformation was performed before sending the data (phase lost!).

The ESA (European Space Agency) project, Cluster, consists of four satellites closely together, studying the magnetosphere. These satellites can perform relative measurements, e.g. E and B gradients. A project for the near future (to be launched in 1997), Cassini, will study the magnetosphere and the moons of Saturn.

Typical satellite instruments for measuring the electric field are Langmuir probes (Low Freq.), radioantennas (High Freq.) and electron guns (LF); the magnetic field is measured with a flux gate magnetometer (LF) or a search coil magnetometer (HF). Electron density and temperature can be derived from the Langmuir probe data and particle spectrometers determine the distribution functions.
Ionospheric heating

In the ionosphere $1 < T_e/T_i < 2$, there are different densities ($10^5 - 10^{12}$ m$^{-3}$), temperatures etc. as a function of time (day-night cycle) and height. Because of the steady state of the plasma with equilibrium and the fact that boundaries are far away, makes the ionosphere a fine laboratory for plasma research. This research is done by perturbing the plasma very strongly (by high RF power) and measuring the secondary effects on the ground. This is called ionospheric heating.

The traditional technique uses refraction and reflection of HF pulses and is still done in Lycksele. At much higher frequencies (UHF & VHF) only a weak scattering is obtained from statistical fluctuations in the plasma, i.e. thermally excited waves whose wavefronts can reflect the probing radar wave (compare with Bragg-reflection in solid state physics). This technique is used by the EISCAT radar. Another technique is to use HF pulses to produce a local enhancement of the plasma waves (heating in Tromsø). It is found that the plasma also reradiates radiowaves (observed from Kiruna), and this makes life easier. See also the figure below.
Non-linear effects

From the Boltzmann equation and the Maxwell laws, completed with charge- and currentdensities, you get solutions that are waves. The equations are non-linear, so solving them is very difficult and simplifications are necessary. You can however obtain a dispersion-relation ($\omega = \text{in}, e = \text{electron}, i = \text{ion}$):

$$\omega = c^2 k^2 + \omega_{\text{plasma}}$$

Using energy and impulses conservation and the fact that

$$|\vec{k}_0| = \frac{V_i}{c} |\vec{k}_e| < |\vec{k}_e|$$

you can see that for a photon to plasmon, phonon transition

$$\omega_o = \omega_0 - \omega_i \ \wedge \ \vec{k}_o = - \vec{k}_i$$

With this you can obtain the ion-frequency. From the fourth harmonic (very narrow line at four times the cyclotron frequency) you can determine this cyclotron frequency and therefore the magnetic field $B$. This technique is developed in this group, but is used worldwide now. A huge installation is being planned (5000 km) especially for these non-linear effects.
Acknowledgements

We owe thanks for the organization of this interesting visit to prof. R. Boström and all the other persons who contributed to this visit.
Introduction

"Chalmers Tekniska Högskola" was founded in 1829 and has become the second largest technical university in Sweden. The department of Technical Physics, which is very much related to the department of Physics of Göteborg University, is placing emphasis on research in semiconductor and solid state physics. In fact, a new Center for Microelectronics is being built which will incorporate both physical and electronic engineering.

Our host this day was Michael Ekenstedt, who guided us through research projects in creation, characterization and modelling of semiconductor devices, ion implantation, nanometer structures and nanometer microscopy.

Molecular Beam Epitaxy
(Thorvald Andersson, Michael Ekenstedt and Jan Thordson)

The department possesses two MBE machines. These machines are being used to grow semiconductor devices, mainly InGaAs material.

One of the technical difficulties of MBE is the measurement of the substrate temperature, which is an important growth parameter. For temperatures higher than 500 °C, a pyrometer can be used. For lower temperatures a probe has been developed, consisting of two thermocouples, one for measurement and one for measuring the temperature gradient in the probe. This gradient is then compensated for by heating the probe. This probe can measure the temperature of the substrate with an accuracy of ± 2 °C. Because it makes contact with the substrate it is not an in situ technique.

An important research activity lies in the field of growth of layers with a slightly mismatched lattice constant, for example GaAs on Si. The so called critical layer thickness is the thickness of the growth layer when this layer is just able to adapt itself to the substrate. This critical layer thickness can be measured using a RHEED (Reflection High Energy Electron Diffraction) gun and screen, where one can see the change of the diffraction pattern when the surface obtains a different
lattice parameter. The critical layer thickness can also be measured with photoluminescence techniques.

**Photoluminescence**  
(Shumin Wang and Weignan Chen)

In quantum well structures, for example a thin layer of GaAs between layers of AlGaAs, there is a decrease of band gap in the thin layer. This can be measured with photoluminescence. A laser with ample energy excites the electrons and holes, which will recombine whilst emitting a photon with a particular energy corresponding to the band gap. With the aid of a monochromator this energy can be measured. A theoretical model is also being developed for explaining the physics of quantum well structures. The model uses as input a description of the potential energy (square, triangular, parabolic, etc.). By solving the Schrödinger equation for this system a set of wave functions is obtained for the valence electrons. This model permits the presence of an applied electric field, which will shift the energy of the luminescent photons. This model is also useful for optimizing the shape of the quantum well. A new shape is developed and tested in the model. This can be used to create faster and more efficient optical switches.

**Ion implantation**  
(Gillis Holmén)

Three applications of ion implantation are:
1. the implantation of C and N in Si to produce insulating layers in semiconductor materials, which will increase the switching speed,
2. the implantation of Ge in Si to observe the stress relief in the Si crystal,
3. the implantation of doping material in a semiconductor (this application is no longer of importance in CTH).

For ion implantation the CTH possesses 5 ion accelerators, ranging from 1 keV to 5 MeV. The upper border of the energy is obtained by a tandem Van der Graaff accelerator. The characterization techniques used are Rutherford BackScattering (fully automatic), Transmission Electron Microscopy, SIMS and Auger spectroscopy.
Nanometer Laboratory
(Bengt Nilsson)

This laboratory has an open structure. The facilities are operated by only two men, whilst these can be used to service several scientists and also students. Among the products of this nanometer laboratory are high Tc superconducting devices, distributed feedback lasers and special very small holographic structures. The laboratory has also produced the logo of the university on a small scale. The smallest structures on this logo, as displayed in figure 1, are around 50 nm.

Microscopy and Microanalysis
(Anders Thölén, Electronic materials; Eva Olsson, José Alarco and Lars Bengtsson)

Scanning Probe Microscopy Laboratory
(Håkan Olin)

These groups possess facilities for Scanning and Transmission Electron Microscopy, Scanning Tunneling Microscopy and Atomic Force Microscopy. The instruments allow the characterization of surfaces as well as internal microstructures. The aim of the research is to relate the microstructure to physical properties and to understand how fabrication conditions influence the microstructure. The obtained knowledge provides the possibility to manipulate the microstructure on an atomic scale and thus enables the control of physical properties of condensed matter.
Scandinavia study tour

One of the projects concerns Josephson junctions for SQUIDs (Superconducting Quantum Interference Devices) based on high temperature superconducting YBa$_2$Cu$_3$O$_{7-x}$ (YBCO). Successive layers of YBCO, SrTiO$_3$ are deposited by a laser deposition technique and subsequently patterned to form an edge, see figure 2. CaRuO$_3$ and YBCO are thereafter deposited and a superconductor-normal metal-superconductor junction is thereby formed.

![Diagram of film deposition process](image)

**Fig. 2**: *production process of high $T_c$ Josephson junction*

The interface microstructure is crucial for the behaviour of the junction. An optimal junction is uniform but electron microscopy reveals the presence of direct contacts the existence of direct contacts (shorts between the bottom and top YBCO layers) and insulating particles along the interface, see figure 3. The studies show that the structure of the patterned YBCO edge is instrumental in determining the structure of the junction. The observations are currently used for the optimization of the edge Josephson junctions.

**Acknowledgements**

We would like to thank Michael Ekenstedt and all the other persons who contributed to this visit.
Scandinavia study tour

Fig. 3: interface defects in the Josephson junction

Fig. 4: a realistic picture of figure 3
N.V. Samenwerkende elektriciteitsproduktieden

Sep is het samenvoudigingsverband van de vier Nederlandse bedrijven die voor de openbare voorziening grootschalige elektriciteit opwekken. Deze vier eigenaren van de elektriciteitscentrales zijn de aandeelhouders van Sep.

Om deze doelen te bereiken is coordinatie en planning van de productie op landelijke schaal noodzakelijk. Daarom werken de vier produktiedenissen nauw samen. In die samenwerking speelt Sep een centrale rol.

Zo adviseert Sep de produktiedenissen in tol van zaken, bijvoorbeeld over nieuwe produktietechnieken en milieuspecifiek. Maar ook in de dagelijkse bedrijfsvoering is Sep actief. Vanuit het coördinatiecentrum in Arnhem wordt de productie in alle Nederlandse centrales gecontroleerd op elkaar afgestemd, zodat zo goedkoop mogelijk geënergeerd wordt. Sep beheert het landelijk koppelingssysteem over elektriciteit, wordt geënergeerd van de productiecentra naar de afnamegebieden. Ook regelt Sep de centrale inkoop van brandstoffen en de in- en export van elektriciteit.

Daarnaast heeft Sep een belangrijke taak in de planning en beleidsvorming. Elk twee jaar stelt Sep het Elektriciteitsplan op. Daarin staan de maatregelen vervolg die ervoor moeten zorgen dat het totale produktiedepot ook in de toekomst een optimale samenstelling heeft. In deze plannen zet Sep tekenen voor de komende twintig jaar de strategie uit van de sector.
Facts and figures

The MAX-LAB is a part of the University of Lund

It's staff consists of the following number of people:
- Technical Staff : 15 (20)
- Accelerator Physics : 3
- Visiting Scientist : $\approx 200$ / year

It's yearly budget is:
- Operating budget : $\approx 1$ million $/$ year
- Instrumentation : $\approx 1$ million $/$ year

The total beamtime is used for the following research-subjects:
- 60 % Synchrotron radiation
- 25 % Nuclear Physics
- 15 % Accelerator Physics

MAX characteristics

MAX I:
- in operation since 1976.
- maximum energy: 500 MeV per electron.
- injector: race-track microtron ( 100 MeV )
- 8 beamlines for synchrotron radiation
- extraction path for nuclear physics experiments
- maximum storage time for electrons: $\approx 6$ hours

MAX II:
- under construction ( assembled mid 1994, in operation mid 1995 )
- maximum energy: 1.5 GeV per electron
Scandinavia study tour

- injector: MAX I synchrotron (500 MeV)
- 10 beamlines for synchrotron radiation
- maximum storage time for electrons: ≈ 10 hours
- local computers for measuring and controlling

**Synchrotron radiation**

At the MAX-Laboratory synchrotron radiation is generated by the acceleration of charged electrons. These electrons are moving with approximately the speed of light and due to that the intensity of the radiation will be focused in the following way (see figure 1):

![Fig. 1: Radiation cone from an electron moving with the speed of light](image)

The angle is equal to \(1/\gamma\), with \(\gamma\) given by:

\[
\gamma = \frac{E}{m_0 c^2} = \frac{500 \text{MeV}}{(0.5 \text{MeV}/c^2) c^2}
\]

The spectral distribution of the synchrotron radiation has the following characteristics:

- Zero intensity below a certain wavelength.
- Fast increase in intensity after which a slow decrease follows.

An example of the spectral distribution is given in figure 2.
Instrumentation used for synchrotron radiation experiments

Wiggler

In order to reduce the angular spreading of the emitted synchrotron radiation the electrons are wiggled in the trajectory section by using permanent magnets which are placed in the following way (see figure 3):

When a strong field and a small number of magnets are used little or no interference is obtained, while at small fields and a large number of magnets interference of each radiation source in the wiggler occurs. This interference can cause the synchrotron radiation to be concentrated in a narrow band around the fundamental wavelength of the wiggler. This radiation is more or less coherent.
Monochromator

The monochromator that is mostly used at the MAX-lab is a toroidal or spherical grating monochromator. These types of monochromators are grazing-incidence monochromators, and are used in a wide range of frequencies of the synchrotron radiation.

An example of the toroidal-grating monochromator is shown in figure 4.

![Diagram of a toroidal grating monochromator]

*Fig. 4: Example of a toroidal grating monochromator*

The angle between the mirror and the lightbeam is about 2°

Experiments done with synchrotron radiation

Photo Electron Spectroscopy (PES)

With PES one looks at the binding energies of electrons in a metal. This is done by sending photons with a selected frequency to the metal. When the photon energy is larger than the binding energy of the electron, an electron will be emitted (see figure 5).
The energy of the emitted electron \( (E_{\text{electron}}) \) can be measured, and with this energy the binding energy \( (E_{\text{bind}}) \) can be calculated with this formula:

\[
E_{\text{bind}} = h \nu - E_{\text{electron}} - \phi
\]

In this formula \( \phi \) stands for the workfunction in the metal.

The advantage of synchrotron radiation for PES is that from a large range of frequencies a 'single' frequency can be selected. In this way one can select a single atom layer to analyse at a time.

**Soft X-Ray Spectroscopy**

Soft X-ray spectroscopy is used for the study of subjects like
- Valence band structures in solids
- Relaxation effects in solidification
- Local electronic structure in larger molecular systems

**Molecular Dynamics and Structures**

The molecular dynamics and structures are studied by fluorescence of the molecules under investigation.

The time resolution is achieved by using 100 ps pulses with a separation of 108 ns. The molecule broadens the pulse and can also change its polarization. This principle is illustrated in figure 6. From the broadening and the new polarization you can get information on the structures and the timescale of the dynamical processes in molecules (e.g. a protein-molecule).
Nuclear Physics

For the nuclear physics experiments the MAX I synchrotron is not used as an accelerator but as a pulse stretcher. A pulse stretcher transforms a short electron pulse with a reasonably high 'amperage' into an electron pulse with a much longer duration and a lower 'amperage'. For example: a milli-ampere 1 µs pulse can be stretched into a nano-ampere 15 ms pulse.

The MAX I synchrotron in the stretcher mode has the following characteristics:
- Beam quality after stretcher
  \[< I > = 50 \text{ nA}\]
  \[< \text{duty factor}> = 0.75\]

The experiments done with the synchrotron in the stretcher mode include reactions like:
- \((\gamma, p)\), \((\gamma, n)\) and \((\gamma, \gamma)\)

An example of the \((\gamma, p)\) reaction is the "C(\gamma, p)"B. With this reaction the absolute differential cross section at angles between 30° and 150° with respect to the incoming photon beam was determined.
The characteristics for the photon beam were:
\[<E_\gamma> = 58 - 64 \text{ MeV}\]
\[\Delta E_\gamma = 300 \text{ keV}\]
\[N_\gamma = 5 \cdot 10^6 \text{ MeV}^{-1}\text{s}^{-1}\]

By comparing the results from the \(^{12}C(\gamma,p){^7}B\) reaction with the results from the \(^{12}C(e,e'p){^7}B\) reaction one gets some information about the nuclear structure which is compared with the nuclear shell model.

An example of the \((\gamma,n)\) reaction is the \(^{4}\text{He}(\gamma,n)^{4}\text{He}\). With this method you also determine the cross section at different angles with respect to the incoming photon beam. The neutrons were detected using the time-of-flight method.

**Control chamber**

**Acknowledgements**

Finally we would like to thank everyone at the MAX-Laboratory for the organization of an interesting and inspiring visit.
Foundation FOM

Working at the international front of science

A job as a PhD-student at the Stichting voor Fundamenteel Onderzoek der Materie (FOM) (Foundation for Fundamental Research on Matter) is a good investment for a further career in research. This fact is evident from an analysis of the careers of PhD's which have left FOM after they have completed their graduate research. FOM is the largest non-profit organization in the field of physics in the Netherlands, employing over a thousand people. PhD-students account for 40% of FOM's workforce. They generally come into contact with FOM through research projects for which university professors or senior lecturers have been granted funds through FOM. Projects last four years, in principle, the period allocated for PhD-research. In this way FOM and other associate organizations in the so-called second flow funding circuit can provide extra posts for researchers at the universities. More than half of the PhD-graduates who leave FOM make their career in industry. Philips, Shell and computer or software companies have been the largest employers in the commercial sector in the last few years. Universities themselves and FOM took over 15% of PhD-graduates onto the staff. About 20% went abroad to take post-graduate posts.

The FOM organization

The FOM Foundation, which falls under the Dutch Organization for Scientific Research NWO, has two fully owned research institutes, the FOM Institute for Atomic and Molecular Physics (AMOLF) in Amsterdam and the FOM Institute for Plasma Physics Rijnhuizen in Nieuwegein. Besides this, FOM is a partner in the National Institute for Nuclear and High Energy Physics (NIKHEF), which has laboratories in Amsterdam and Nijmegen, in the Nuclear Accelerator Institute (KVI) in Groningen and in the Delft Institute for Microelectronics and Submicron technology (DIMES) in Delft. A second string to FOM’s bow are the working groups (a total of approximately 150) at all universities which have a physics faculty (including applied physics and in some cases such courses as materials science, electrical and mechanical engineering). FOM has cooperative agreements within the Netherlands with mathematicians, information scientists, chemists and with the Technology Foundation (STW), and is responsible for running government programmes in the field of IC-technology and high Tc superconductors. Outside the Netherlands FOM participates in European particle physics in CERN near Geneva and DESY in Hamburg, and in the European thermonuclear fusion programme which includes the JET facility in England. At institutional and working group level there are many forms of cooperation with institutions and colleagues in a large number of countries in and outside Europe. In many cases, working at FOM means working at the international front of science.

More information

Further information about career possibilities with FOM can be obtained from the Central Personnel Office, Stichting FOM, P.O. Box 3021, 3502 GA Utrecht, the Netherlands. Tel.: +3130923211, Fax: +3130946099.