Modern Methods in Experimental Physics: Modern developments in X-Ray and Neutron Methods for Science and Technology for Master

Vorlesung und Übung (20 135) - 3-stündig, ECTS: 5

Dozenten:	Alexei Erko
Sprache:	Englisch
Zeitraum:	13.10.2009 bis 09.02.2010
Haupttermine:	Dienstag 16 - 18 Uhr - Arnimallee 14 SR E1 (1.1.26)
maximale Teilnehmerzahl	unbeschränkt
Terminhinweis:	Beginn: 13.10.2009, Begleittermin: Donnerstag ab 16 Uhr – Albert-Einstein Str. 15, Adlershof, BESSY II, oder Wannsee, Glienicker Str. 100
Inhalt:	Modern sources of synchrotron radiation (SR) and neutrons are very powerful tools in a wide range of important research activities, ranging from biology and medicine to solid state physics and micro/nano-technology. This Lecture Series will provide a basic knowledge of the operational principles, control and manipulation of SR and neutron beams as well as describing their main characteristics. X-ray and neutron optics will be described in detail, as well basic experimental techniques such as absorption, photoelectron spectroscopy, diffraction analysis and wide/small angle scattering for both types of beams. Future perspectives for new source developments, i.e., X-ray Free Electron Lasers (FEL), Energy-Recovery X-ray Sources and new Neutron Sources will be included into the programme. Practical sessions are planned to take place at the at BESSY II storage ring in Adlershof and the neutron source at Wannsee to provide the students access to state-of-the-art instrumentation and methods.
Zielgruppe:	Physiker, Chemiker
Literatur:	1. “Handbook on Synchrotron Radiation”, ed. E.E. Koch, North-Holland Publishing Company, 1983 2. “Modern developments in X-Ray and Neutron optics”, Eds. A. Erko, Th. Krist, M. Idir, A. Michette, Springer, 2008 3. “Diffraction X-Ray Optics”, A. Erko, V. Aristov, B. Vidal, Institute of Physics Publishing, 1996 4. “Neutron Optics”, Sears V. F., Oxford University Press, 1989 5. “Neutron Physics”, Ed. G. Hoehler, Springer Tracts in Mod. Phys. 80, Springer Berlin, 1977

October 2009

13.10 **Introduction: Prof. Dr. Anke Rita Kaysser-Pyzalla, Prof. Dr. Alexei Erko**
X-Rays and Their Properties.
The lecture will describe the basic properties of X-rays. X-ray emission processes will be considered, including bremsstrahlung and characteristic radiation. Laboratory X-ray sources, synchrotron radiation, plasma emission, X-ray lasers and Energy-Recovery Linear Accelerators will be covered. Brief descriptions of the main properties of each of these X-ray sources will be given. Special attention will be paid to synchrotron storage rings. The particular properties of synchrotron radiation from bending magnets as well as construction principles of insertion devices (wigglers and undulators) will be discussed.

20.10 **Prof. Dr. Alexei Erko**:
X-Ray Interactions.
The scattering and absorption of X-rays via atomic processes will be discussed, relating these to microscopic and macroscopic properties. The analysis will be carried out using Kramers-Kronig relations. The various possibilities for x-ray optics will then be discussed. Special attention will be paid to principles and constructions of micro/nano X-ray optics for high-resolution imaging and focusing. In the second part of the lecture one of the most powerful methods with synchrotron radiation, Extended X-ray Absorption Fine Structure (EXAFS), will be discussed in detail.

27.10 **Dr. Rolf Follath**
Beamlines and Monochromators
This lecture discusses the generation and conditioning of synchrotron light for user experiments. It starts with an overview of dipole and insertion devices in the storage ring and outlines their particular properties. The second part recapitulates relevant optical basics and their impact on beam formation and monochromatization before various types of monochromators for the soft- and hard X-ray regimes are introduced. Guidelines for beamline design show how opposing demands lead to a specific beamline design. Commissioning results illustrate the capabilities of the BESSY beamlines and identify common pitfalls in all day operation. A short introduction to the operation of soft X-ray beamlines and the graphical user interface at BESSY ends the lecture.

November 2009

3.11 **Dr. Antje Vollmer**
Photoemission Spectroscopy
This lecture is dedicated to the principles and applications of X-ray and UV photoemission spectroscopy (XPS and UPS). It will start with an introduction into the fundamental processes of photoemission followed by a discussion of the diversity of information that can be retrieved by a detailed analysis of the obtained data. Transfer of the theoretical principles into practice will be demonstrated by examples coming from a variety of research areas, e.g., solar cells, accelerator physics, organic electronics. In addition, particular emphasis will be given to the use of synchrotron radiation and its advantages/disadvantages over laboratory radiation sources.

10.11 **Dr. Bernd Löchel**
X-Ray Micro and Nano Technology
Part 1 of the lecture is an introduction to X-ray lithography and X-ray supported micro/nano fabrication. Process details of lithography will be given and the fabrication of X-ray masks will be discussed. Special characteristics of this type of lithography along with demo masks will be shown. This demonstration will identify the physical and technical limits. Part 2 of the lecture will discuss and present applications of X-ray lithography and X-ray micro/nano fabrication. It will also discuss topics such as advantages/disadvantages, technical and economical limits for the fabrication process using synchrotron radiation, and future developments. For demonstration, assembled Micro Harmonic Drive Gears will be presented.

17. 11 **Dr. habil. Oliver Rader**

Angle-Resolved Photoemission

Building on the lecture by A. Vollmer, angle-resolved photoemission from single-crystalline surfaces will be introduced. Electronic band structure and k-space will be reviewed, and the photoemission process will be divided into three steps such that conservation laws become apparent. Selection rules will be addressed as well as the different methods for obtaining band structures in two and three dimensions. Through electron energy broadening and the concept of the wave vector, the shapes of the angle-resolved photoemission spectra will be described completely. Finally, applications will be presented for volumes, surfaces, quantum wells and quantum wires of magnetic and nonmagnetic metals.

24.11 **Prof. Dr. Peter Fratzl**

Scanning-SAXS for biomaterials characterization

The outstanding properties of biological tissues, such as wood or bone, are related to their hierarchical structure and to a structural adaptation at all levels of hierarchy. It is, therefore, essential to characterize the structure at all levels to understand the complex behaviour of such tissues. Structures down to the micrometer level are accessible to light or scanning-electron microscopic observation. To characterize sub-micrometer structures, other methods such as transmission electron microscopy or x-ray scattering are necessary. The availability of extremely brilliant synchrotron x-ray sources has led to the development of the new techniques of scanning small-angle x-ray scattering (SAXS) and scanning x-ray microdiffraction (SXRD), which are capable of providing structural information on the micrometer and the nanometer level, simultaneously. The principle is that the specimen is scanned across an x-ray beam with a diameter of few microns or even less. Measuring the x-ray absorption at each position provides an image of the specimen (micro-radiography) with resolution similar to light microscopy, in the micrometer range. Moreover, the x-ray scattering pattern is analyzed at each specimen position to provide parameters characterizing the structure in the nanometer range. The lecture gives principles of the technique and shows applications for the study of bone, lobster cuticle, plant tissues and other biological materials.

December 2009

1.12 **Dr. Ulrich Schade**

Infrared Spectroscopy

This lecture will introduce the basic principles of infrared spectroscopy with synchrotron radiation and the concept of Fourier transform spectrometers. The first part of the lecture will start with a short introduction to vibrational spectroscopy. It will discuss how this relatively old analytical method can benefit from the unique properties of synchrotron radiation to address questions in modern life and materials sciences. The second part of the lecture is dedicated to a series of experiments which were conducted at the BESSY II spectromicroscopy/THz beamline. This includes time-resolved experiments, confocal microscopy, ellipsometry and linear THz spectroscopy.

8.12 **Dr. Karsten Holldack**

TeraHertz Spectroscopy

After a short introduction to the properties of electromagnetic radiation in the THz spectral range, the lecture will introduce the interesting scientific opportunities using THz pulses as probes and tools in condensed matter physics. An overview of instrumentation will discuss the principles of laser-based and accelerator based THz sources including electrostatic and rf-LINAC based Free Electron Lasers (FEL) and storage rings including the generation of mm and sub-mm waves with short electron bunches at BESSY as well as their extraction and detection. The important role of THz pulses emitted from relativistic electron bunches for accelerator timing control will be discussed. From a scientific viewpoint, recent condensed matter applications of THz radiation obtained with ultrahigh resolution spectroscopy as well as the study of ultra-fast phenomena in optical pump/THz probe and other experimental setups addressing contemporary physics in correlated systems will be discussed using also very recent examples from the dedicated THz beamline at BESSY II.

15.12 **Prof. Dr. Alexander Föhlisch**
X-Ray Lasers
The concept of Free Electron Laser (FEL) sources yields high brilliance, ultra short radiation pulses (~20-200 fs) tunable over a wide photon energy range from the vacuum ultraviolet (VUV: 10-200 eV), soft-X-rays (100-1500 eV), to X-rays (above 1500 eV). The FELs at Hamburg and the Linac Coherent Light Source (X-ray: LCLS) at Stanford will provide excellent conditions for this research. A fusion of the advantages of the FEL (brilliance) and the optical lasers (pulse definition and synchronization) is aimed at in the concept of a high gain high harmonic seeded FEL, where high harmonics of an optical fs-laser system are amplified in a cascaded FEL scheme. Thus, the powerful tools of fs-laser physics (pulse shaping, phase stabilization, etc.) will be transposed and imprinted onto ultra short pulses in the soft-X-ray spectral range. In particular experiments using the high peak brilliance of FEL,s and time resolved pump-probe experiments are key areas of future research.

January 2010

5. 1. **Prof. Dr. Bella Lake**
Introduction to neutron scattering
This lecture will cover the basic principles of neutron scattering and describe the concept behind various instruments. The lecture will begin with a description of the properties of the neutron and how it interacts with matter. Then the two main sources of neutrons - reactor and spallation sources - will be described. The neutron will be compared to other scattering probes such as the electron and x-rays and the advantages and disadvantages of neutron scattering will be discussed. The concept of neutron scattering cross-sections will be introduced and some of the mathematical formulae will be derived. Finally, short descriptions of a variety of neutron scattering instruments will be given.

12. 1. **Prof. Dr. Susan Schorr**
Neutron Diffraction
The lecture will continue the description of the basic principles of a type of *elastic* neutron scattering that is neutron diffraction. Special attention will be paid to the diffractometer concept at a continuous wave source and a spallation neutron source including a discussion on monochromatizsation and resolution. The structural information which can be obtained from a neutron diffraction pattern will be discussed. The method of Riveted analysis with special regard to the concept of the average neutron scattering length will be explained. Finally different examples will be shown.

19. 1. **Dr. Konrad Siemensmeyer**
Magnetic Neutron Diffraction
The introduction to this lecture gives an overview of the magnetic properties of matter and the microscopic background such as the origins of permanent magnet moments and their interactions. Different interactions and crystal symmetry lead to a large variety of long range ordered magnetic structures. Research on magnetic structures is of fundamental interest, but the magnetic properties of matter also find many applications in daily life. Magnetic neutron diffraction is the key experimental tool in determining magnetic structures and the lecture gives an introduction to this technique. The magnetic cross section will be discussed in detail. Examples will be given to show how the magnetic structure information is extracted from diffraction data.

26. 1. **Prof. Dr. Bella Lake**
Inelastic Neutron Scattering
This lecture will cover the basic principles of inelastic neutron scattering, as well as describing how such experiments are performed and the type of information that can be gained. The lecture will begin with an introduction to the mathematical basis of neutron scattering, starting with the basic conservation equations and going on to discuss the inelastic neutron scattering cross section along with the specific cross sections for phonons and magnons. After this, specific instruments for inelastic neutron scattering measurements will be described. The basic concepts of the triple-axis spectrometer will be discussed and the instrument components will be described. The time-of-flight spectrometer, a new instrument for inelastic measurements, will also be discussed and compared to the triple-axis spectrometer. Finally, examples of real experiments will be given.

February 2010

2. 2. **Dr. Th. Krist**:
Neutron Optics
This lecture will introduce the basic principles of neutron optics including the polarization of neutrons. The possibilities for controlling the flight direction and the polarization state of neutrons will be discussed. The concept of neutron supermirrors will be explained, forming the basis of a whole family of neutron optical elements which are important in carrying out real experiments, including neutron guides, benders, polarizers, and focusing devices. Other techniques which are employed to polarize and focus neutron beams will also be described. Finally, the technique of neutron reflectometry will be introduced with emphasis on the instrument at which the practical work will be carried out.

9. 2. **Prof. Dr. Wolfgang Treimer**
Introduction to Neutron Tomography
The fundamental mathematics (Fourier and Radon transform, Slice theorem, Shannon theorem, reconstruction techniques) of computerized tomography will be presented and explained in detail. In this lecture a survey of the most important imaging signals based on absorption, phase contrast, energy dependency and the polarization state of neutrons will be given. Instrumental equipment, special features, spatial resolution, etc., will be discussed as well as examples and applications in fundamental and applied physics.