Fundamentals of Experimental Spectroscopy (1 Å - 10 μm).

Prof. Eugene Ragozin

Goals and objectives

The aim of this lecture course is to outline the basics of experimental spectroscopy in a broad spectral range, from the infrared to hard X-rays. Special effort is made to emphasize the common ideas that underlie the methods and operation of optical elements throughout this range of electromagnetic spectrum. The main specific objectives are as follows:

- to describe the operation of the main spectroscopic instruments and components like diffraction gratings, Fabry–Perot interferometers, prisms, mirrors, crystals, etc.;
- to give an overview of the radiation sources employed and investigated in modern physics research;
- to outline the main physical principles that underlie the operation of diverse radiation detectors;
- to provide examples of spectroscopy-based experiments that were landmarks in physics.

Syllabus

Lecture 1. Introduction

Electromagnetic wavelength scale. Wavelength, frequency, and energy units. Specific features of IR, visible, UV, VUV (XUV) and X-ray spectral regions. The objects and goals of experimental spectroscopy. Basic notions and characteristics of dispersion spectral instruments. Instrument function.

Lecture 2. Use of refraction

Refractive dispersion and focusing elements in the visible, UV, and X-ray spectral regions. A prism and a prism sequence. Classical prism spectrograph. Fundamental prism resolution limit.

Lecture 3. Plane diffraction grating

Intensity distribution. Grating equation. Angular magnification. Angular dispersion. Plate scale. Theoretical and practical resolving powers. Curvature of spectral lines. Blaze angle. Spectrometers with a plane diffraction grating.

Lecture 4. Concave diffraction grating

Generalized optical path function. Spherical diffraction grating. Equations describing the locations of horizontal (spectral) and vertical foci. Rowland circle. Astigmatism. Resolving power and optimal width of a concave grating. Wadsworth mount. EUV spectroheliograph.

Lecture 5. EUV grating spectrometers

Concave grating at grazing incidence. Varied line-space (VLS) grating. Harada spectrograph. Plane VLS-grating spectrometers and monochromators. Stigmatic spectrometers. Gaining spatial resolution.

Lecture 6. Transmission diffraction grating

Amplitude and phase transmission gratings. Free-standing gratings for the EUV and X-ray regions. Pinhole and large-area gratings. Grating equation. Equations describing the locations of horizontal (spectral) and vertical foci. Aberrations. Diffraction-order energy distribution. Regular and pseudo-random support structure.

Lecture 7. Fabry–Perot interferometer

Brief historical overview of multiple-beam interferometers (Fabry–Perot interferometer, Lummer-Gehrke plate, Michelson echelon). Fabry–Perot interferometer: intensity distribution, contrast ratio, angular dispersion, free spectral range, spectral resolution. Comparison of the instruments with spatial spectral decomposition.

Lecture 8. Interference filters, FECO fringes, and surface roughness

Interference filter as a non rigorous spectral filter. Fringes of equal chromatic order (FECO fringes). Determination of optical surface roughness using FECO fringes. Simplest surface roughness model. Intensities of specular reflection and diffuse scattering by a “rough” surface. Total integral scattering (TIS) method. Power spectral density (PSD) function.

Lecture 9. Introduction to EUV/soft X-ray optics

Permittivity (dielectric constant) of substance in the EUV. Causality, stationarity, locality. Kramers-Kronig relations. Atomic scattering factors. Absorption and refractive index of materials. Absorption edges of the elements. Absorption of the air. Requirements on the residual vacuum.

Normal- and grazing-incidence reflection in the EUV. Critical angle and total external reflection.

Lecture 10. EUV/x-ray multilayer optics

Multilayer mirrors. Multilayer polarizers. Aperiodic multilayer structures. Broadband multilayers and polarizers. Stigmatic spectral imaging in the EUV. Aperiodic multilayer mirrors as attooptical elements. Transparent films and (multilayer) absorption filters.

Bragg equation. Crystal spectrographs.

Fresnel zone plates. Refractive X-ray lenses. X-ray refractive prism spectrograph.

Lecture 11. Radiation detectors I

Classification of detectors according to the physical operating principle. Detector parameters. Detectors with internal and external photoeffect. Detectors with spatial and temporal resolution. Modulation transfer function. Absolute calibrated detectors.

Lecture 12. Radiation detectors II

Luminescence detectors. Image transfer by optical fiber discs. X-ray fluorescence. X-ray calorimeter. Crossed delay line (CDL) detector.

Lecture 13. Radiation sources I

Thermal sources. Field oscillator density. Amplified spontaneous emission from an amplifying column. Lasers. Optical frequency comb.

Laser-produced and electric-discharge plasma sources. Charge exchange and charge-exchange spectroscopy. Beam-foil spectroscopy. Elementary processes involving multiply charged ions. Plasma diagnostics from the line spectra of multiply charged ions.

Lecture 14. Radiation sources II

Soft X-ray plasma lasers. High-order harmonics of laser radiation. Frequency comb in the EUV. Synchrotron/undulator radiation and free-electron lasers.

Lecture 15. Elements of laser spectroscopy

Absorption spectroscopy. Fluorescence method of laser spectroscopy. Doppler-free spectroscopy. Bennett holes. Lamb dip (hole). Two-photon spectroscopy. Spontaneous and stimulated Raman scattering.

References

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