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INVERSE PROBLEMS NEWSLETTER

Principles of Plasma Spectroscopy
A.L. Osterheld

Kinetic Theory of Granular Gases
Emmanuel Trizac

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Chapter 1

Introduction

This book presents advances in x-ray spectroscopy of:

- plasmas interacting with a laser radiation;
- laser-induced plasmas.

We focus mostly (but not exclusively) in advances in x-ray spectroscopic diagnostics. These advances are mainly due to the progress in theoretical and experimental studies of the shapes of x-ray spectral lines. The primary reason is that the spectral line shapes are practically independent of the choice of a particular model of the plasma state. This is a clear distinction from other diagnostics that depend on the choice of the plasma state, which could result in a large uncertainty.

The first theoretical underpinnings for analyzing x-ray spectra for plasma diagnostics were developed for astrophysical purposes. It is considered that the beginning of the observational x-ray astrophysics dates to the year 1962 where x-ray binary source Scorpius X-1 was discovered [1]. In the intervening dozens of years, tremendous progress has been made in observational x-ray astrophysics—see, for example, review [2] and references therein. X-ray spectroscopy enables studying a wide variety of astrophysical objects. In particular, diagnostics based on x-ray spectral lines are used, for instance, for measuring densities, temperatures, ionization balance, and abundances—see, for example, review [3] and references therein.

These techniques were further developed and used for diagnostics of various laboratory plasmas. X-ray spectroscopy is a set of multi-parameter methods for plasma diagnostics. In its traditional form it can provide information, for example, about the electron density, the temperature of electrons and ions, the densities of radiating atoms and ions, and the ionization balance—see, for instance, review [4], as well as book [5] and references therein.

The most fruitful results in the traditional x-ray diagnostics of laser plasmas were achieved due to advances in the theory of the Stark broadening of ion spectral lines in plasmas—see, for example books [6–9]. A brief overview of some of these

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theoretical advances is presented in appendix A of the current book. These advances provided opportunities for relatively accurate measurements of the electron density, as well as of the temperature of electrons and ions.

More recent advances in theoretical and experimental laser plasma diagnostics based on the x-ray spectral line shapes have significantly expanded the scope of measured parameters—see, for instance, book [9] and references therein. It became possible to study the development of Langmuir waves, ion acoustic waves, and transverse electromagnetic waves induced by various laser–plasma interactions. Also, these advances enabled the possibility to study other nonlinear processes caused by laser–plasma interactions, such as, for instance, parametric decay instabilities. Last, but not least: it has also become feasible to obtain information about the rates of charge exchange between multicharged ions—information virtually inaccessible for other methods. Details on all of these advances can be found in papers [10–35] (listed in chronological order) and are presented in the current book.

Additional important information can be obtained through the polarization analysis of x-ray spectral line shapes. These methods, presented in papers [36–38] were developed for powerful Z-pinches, but they are applicable also for laser plasmas.

The practical importance of this entire research area is the following. First, it is indispensable for one of the two major directions in the quest for controlled nuclear fusion—namely, for laser fusion. Second, it is an important tool in studying matter under the extreme conditions produced by super-high-intensity lasers. Third, it can provide atomic reference data (such as the rate of charge exchange between multicharged ions) virtually inaccessible by other methods. Fourth, it shows the way to creating plasma-based tunable x-ray lasers. Fifth, it opens up new avenues for laboratory modeling of physical processes in astrophysical objects and a better understanding of intense laser–plasma interactions.

This book is structured as follows. Chapter 2 presents theoretical and experimental studies of charge-exchange-caused dips (X-dips) in profiles of x-ray spectral lines. It also presents the application of the X-dip phenomenon to the experimental determination of rate coefficients of charge exchange between multicharged ions in plasmas.

Chapter 3 is devoted to diagnostics of non-relativistic laser–plasma interactions based on their effects on x-ray spectral line shapes. Most of the attention is given to the phenomenon of Langmuir-wave-caused dips (L-dips) and their applications to measuring parameters of plasmas and of the laser- or laser-caused-fields in plasmas.

Chapter 4 presents theoretical and experimental studies of relativistic laser–plasma interactions based on their effects on x-ray spectral line shapes. The corresponding diagnostics provide, in particular, experimental information about various nonlinear processes in plasmas, such as, for example, the parametric instabilities.

In chapter 5 the discussion is focused on the possibilities of spectroscopic measurements of GigaGauss or multi-GigaGauss magnetic fields, developing during interactions of plasmas with super-intense laser radiation. These possibilities have employed effects of these ultra-intense magnetic fields on the locations and width of L-dips in x-ray spectral line profiles.

Chapter 6 presents concluding remarks. It includes a brief description of several works that did not fit in the scope of chapters 2–5.

The appendices provide additional details on the topics presented in chapters 2–6.

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