Plasma Physics

Alexander Piel

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## An Introduction to Laboratory, Space, and Fusion Plasmas

Springer

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*To Hannemarie,*
*Christoph and Johannes*

# Preface

This book is an outgrowth of courses in plasma physics which I have taught at Kiel University for many years. During this time I have tried to convince my students that plasmas as different as gas dicharges, fusion plasmas and space plasmas can be described in a unified way by simple models.

The challenge in teaching plasma physics is its apparent complexity. The wealth of plasma phenomena found in so diverse fields makes it quite different from atomic physics, where atomic structure, spectral lines and chemical binding can all be derived from a single equation—the Schrödinger equation. I positively accept the variety of plasmas and refrain from subdividing plasma physics into the traditional, but artificially separated fields, of hot, cold and space plasmas. This is why I like to confront my students, and the readers of this book, with examples from so many fields. By this approach, I believe, they will be able to become discoverers who can see the commonality between a falling apple and planetary motion.

As an experimentalist, I am convinced that plasma physics can be best understood from a bottom-up approach with many illustrating examples that give the students confidence in their understanding of plasma processes. The theoretical framework of plasma physics can then be introduced in several steps of refinement. In the end, the student (or reader) will see that there is something like the Schrödinger equation, namely the Vlasov-Maxwell model of plasmas, from which nearly all phenomena in collisionless plasmas can be derived.

My second credo as experimentalist is that there is a lack of plasma diagnostics in many textbooks. We humans have only an indirect experience of plasmas, we cannot touch, hear, smell or taste plasma. Even the visual impression of a plasma is only the radiation from embedded atoms. Therefore, we must use indirect evidence to deduce plasma properties, like density, temperature and motion. Each time my students have grasped the principle of a plasma process, I ask what we can learn about the plasma by studying this process.

In preparing this book, I have been supported by many colleagues. My special thanks go to John Goree, Thomas Klinger and André Melzer for many fruitful discussions which led to the concept of this book and for critically reading selected chapters. Holger Kersten commented on Chap. 11 and permitted photographing some of his gas discharges. Many examples in this book were taken from papers published together with my PhD students and Post-Docs, which I

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Kiel, Germany Alexander Piel
November 2009

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# Acronyms

| | |
|---|---|
| ac | alternating current |
| ADC | analog to digital converter |
| AGM | anode glow mode |
| CCD | charge coupled device |
| CME | coronal mass ejection |
| CRI | color rendering index |
| DAC | digital to analog converter |
| DAW | dust acoustic wave |
| dc | direct current |
| DDW | dust density wave |
| DIAW | dust ion-acoustic wave |
| DL | double layer |
| DS1 | Deep Space-1 |
| D–T | deuterium–tritium |
| EEDF | electron energy distribution function |
| EEPF | electron energy probability function |
| ES-1 | electrostatic code 1 |
| FCC | Federal Communications Committee |
| ICF | inertial confinement fusion |
| ICP | inductively coupled plasma |
| IRC | internal reflective coating |
| IRI | International Reference Ionosphere |
| ITER | International Thermonuclear Experimental Reactor |
| JET | Joint European Torus |
| LASCO | Large-Angle Spectrometric COronograph |
| MHD | magnetohydrodynamics |
| NASA | National Aeronautics and Space Administration |
| NIF | National Ignition Facility |
| NSTAR | NASA solar electric propulsion technology application readiness |
| PDP1 | plasma device planar code |
| PIC | particle-in-cell |
| OML | orbital motion limit |

| | |
|---|---|
| rf | radio frequency |
| RIE | reactive ion etching |
| SMART-1 | Small Missions for Advanced Research in Technology |
| STEREO | Solar TErrestrial RElations Observatory |
| SWOOPS | Solar Wind Observations Over the Poles of the Sun |
| TEXTOR | Tokamak Experiment for Technology Oriented Research |
| TFTR | Tokamak Fusion Test Reactor |
| TLM | temperature limited mode |
| TNT | trinitrotoluene |
| UV | ultraviolet |
| VCR | video cassette recorder |
| WIIa | Wendelstein IIa stellarator |
| W7-A | Wendelstein 7-A stellarator |
| W7-AS | Wendelstein 7 advanced stellarator |
| W7-X | Wendelstein 7-X stellarator |