BOOK REVIEWS

Selection of books for review is based on the editor's opinions regarding possible reader interest and on the availability of the book to the editor. Occasional selections may include books on topics somewhat peripheral to the subject matter ordinarily considered acceptable.

An Introduction to the Physics of Intense Charged Particle Beams

Author	R. B. Miller
Publisher	Plenum Publishing Corporation, 233 Spring Street, New York, New York 10013
Pages	362
Price	$45.00
Reviewer	David A. Hammer

An Introduction to the Physics of Intense Charged Particle Beams is intended to be both a text for graduate students and beginning researchers and a reference source for scientists working in the intense beams field, according to the author as stated in the Preface of the book. I believe that the author has been only partially successful in achieving his goal. My principal reason is a lack of balance between theory and experiment—the overwhelming emphasis of the book is intense beam theory. Considering that the rapid development of this field of research over the last 20 yr has been led by experiments, to my mind this is a serious shortcoming. For this reason, as well as others discussed below, I find the book to be less valuable as an introductory text than it should be, and its value as a reference source is limited by the range of material covered. Nevertheless, because this book is the only one available on intense charged particle beam physics, and because it does have significant strengths, I will very likely ask my students to buy it the next time I teach a course on the subject. Furthermore, I would certainly recommend it to an experienced scientist from another field who wishes to become familiar with various aspects of intense beam theory. As for the value of the book as a reference source to advanced workers in the field, experimentalists will probably find it a useful compilation of theoretical calculations at different levels of complexity on many aspects of intense beam physics. Theorists will probably find it less useful since it is not complete on any subject. Its collection of a few hundred references in one place, though not exhaustive, will probably prove useful from time to time to both theorists and experimentalists. In the following paragraphs, the strengths and weaknesses of the book are discussed in some detail so that the reader may understand the reasons for the above summary remarks.

The most important point in favor of this book is that it exists. Miller recognized the need for a book on the subject of intense charged particle beams, as have many of us, and he provided one with some significant strengths and the rest of us have not. Its coverage is mostly intense beam theory, including both material of a general nature and applications. In the former category are electron and ion diode theory, beam equilibrium and stability theory in vacuum, beam/plasma interaction, including stability theory and current neutralization, and beam/neutral gas interaction. There are only summary discussions of experimental results. Experimentally based formulas are presented concerning high voltage breakdown of various dielectric media in discussions of pulsed power generators (Chap. 2), and of low pressure neutral gas propagation of electron beams (Chap. 5). The three application chapters cover

1. generation of high power coherent radiation by electron beams (but excluding the pumping of gas lasers)
2. collective acceleration of ions by linear electron beams (but not the electron ring accelerator concept or "autoacceleration" of some electrons in a beam to very high energy by the rest of the beam)
3. application of electron and ion beams to inertial confinement fusion (ICF).

Again, these are theoretical discussions with experimental summaries. There are "homework" problems ranging from very simple to very difficult at the end of each chapter.

The strengths of the book are, in general, a large amount of beam theory appearing in one place, although there is nothing that is not available elsewhere, and major portions of the three applications chapters (Chaps. 6, 7, and 8). Each of the latter is worthy of some specific comments. Chapter 6, "High Power Sources of Coherent Radiation," takes up three techniques by which electron beam power may be converted into coherent radiation. Clear physical pictures are presented on magnetron, electron cyclotron laser, and free electron laser systems, followed by analytic calculations, which are followed in turn by discussions of the results. (Unfortunately, the theoretical situation with regard to the free electron laser has been changing so rapidly since the book was written that the section is probably out of date already.) While this chapter suffers from many of the problems described below, including a lack of experimental data to verify theoretical predictions, it is generally quite good. In Chap. 7, which covers "Collective Ion Acceleration with Linear Intense Relativistic Electron Beams," the motivation of the research and physical models of acceleration mechanisms under discussion are well presented. There is also a good overall summary of the experimental situation, although no data are presented. Since there is a monograph on this subject alone (Ref. 42 of Chap. 7), a more complete treatment is not necessary. Chapter 8 takes up the subject, "Particle Beam Fusion Concepts." Following a somewhat foggy introductory description of fusion in general, and ICF in particular, this chapter presents a readable summary on the use of intense electron, light ion, and heavy ion beams to ignite an ICF pellet. The technical level is uneven in the various sections, but it is always high enough to allow an understanding of the relative merits of electrons, light ions, and heavy ions for ICF, and why pellets for each look like they do.

By far the most important shortcoming of this book is the lack of experimental data other than a couple of figures showing "open shutter" photographs of an electron beam propagating in an unspecified gas (Figs. 1.16 and 4.4). Why is there no graph showing how well the current as a function of voltage in a pinched electron beam diode agrees with that predicted by parapotential flow theory (p. 49)? Why are there no data shown to support the alleged agreement between theory and experiment (p. 318) on electron beam power density enhancement when several beams are overlapped at a target after propagating in plasma channels? There are dozens of places in the book where relevant experimental data could have been presented following (or preceding) analyses, which would have substantially increased the value of the book to all levels of reader. Admittedly, this would have increased the length of the book and could easily have doubled the number of figures. However, since this field of research is not mature, and so much intense beam theory was preceded by experiments that needed explanation, it seems that the effort would have been worthwhile. The reader is left with a completely misleading impression as a result of the lack of data at the end of Chap. 5 where a qualitative summary of intense electron beam transport in air is presented. An ~0.5- to 1-T region (presumably for air) is marked "Two Stream Instability," since many workers believe that several effects observed when an intense electron beam is injected into 0.3- to 1-T air are consistent with the presence of that instability. However, most experiments have shown that beam energy transport can be quite high in this pressure range. Perhaps this is because any extra transverse energy introduced in the beam by the instability is balanced by residual beam self-magnetic field in this pressure range. Perhaps it is because of the nonlinear effects that the author discusses. In any event, poor energy propagation efficiency does not necessarily follow from the presence of the two-stream instability.

Another prominent problem of this book is that there are a large number of "small" errors ranging from misspellings (including the author's place of employment on p. 316), to an incorrect reference (33 for Chap. 4), to a missing equation (Eq. 3.50), and a reversed inequality sign (p. 174). However, the alert reader should have no trouble spotting and correcting most of them. Also relatively minor is the use of certain terminology, which is not necessarily known to the reader, without definition or explanation. "Magnetic flashover inhibition" in Sec. 1.2.4 on vacuum diodes and "C-overlap regime" in Sec. 3.3 on space-charge-limiting current are two examples. Occasionally, terms or symbols are not defined when they first appear, but the definition does appear within a few pages. I also found most of the figure captions to be overly brief. Finally, in this discussion of minor problems, referencing is incomplete and some of the omissions are important in my opinion. For example, in the chapter on sources of coherent radiation, the earliest observations of high power microwave radiation using intense beams by Nation[1] and by Friedman and Herndon[2] are not mentioned in the summary. Neither is the earliest work, experimental or theoretical, on current neutralization of intense electron beams in neutral gas.[3]

Of greater importance to me, as one who is likely to use this book as a course text, is the uneven provision of simple physical models and discussion to complement the mathematical treatments that constitute the bulk of the book. Specifically, Chaps. 2 and 4 have calculation after calculation of the space-charge-limiting current and of various kinetic instabilities of a beam in a plasma, respectively, with little or no physics discussion concerning their differences and different consequences. For example, the author could have started the discussion of the two-stream instability with the simplest model (one-dimensional, cold beam, etc.), explained the physical mechanisms responsible for the growth and saturation, and then moved on to more and more complex geometrical configurations (applied magnetic field, two-dimensional variation, etc.) and beam conditions (warm or scattered) in a step-by-step manner, explaining the new consequences at each step. Even without corroborating experimental data, such a technique would have been more easily assimilated by the reader than jumping straight in with a relatively complicated model. As already noted, motivation and physical insight are provided very well in Chaps. 6 and 7. It is too bad this ratio of physics to mathematics was not maintained throughout the book.

Finally, with respect to the book's potential as a reference source for advanced researchers, as is necessary in an introductory text, the depth to which any given subject is taken is limited. Therefore, no subject is complete as it might be in a monograph. I expect the book will be of greater interest to experimentalists who are interested in its large collection of theoretical results in one place, even if they are not from the "most advanced" model, than to the theorist who is trying to come up with the "last word" from an even more advanced model. However, I do expect that both theorists and experimentalists will find the large collection of references useful on many occasions.

In summary, although this book has flaws, it is the only one available, and it has sufficient strengths to make it worth purchasing by a student of intense charged particle beams and, perhaps, by advanced workers in the field as well.

REFERENCES

1. J. A. NATION, *Appl. Phys. Lett.*, **17**, 491 (1970).

2. M. FRIEDMAN and M. HERNDON, *Phys. Rev. Lett.*, **28**, 210 (1972); see also *Phys. Rev. Lett.*, **29**, 55 (1972); see also *Phys. Fluids*, **16**, 1982 (1973).

3. The first published discussion is W. T. LINK, *IEEE Trans. Nucl. Sci.*, **NS-14**, 777 (1967). Still earlier is F. C. FORD, W. T. LINK, and J. CREEDON, Physics International Company Report PIPB-9, dated August 19, 1966.

David A. Hammer has been involved in intense charged particle beam research since 1967, first as a graduate student *at Cornell University (CU), then as a research physicist at Naval Research Laboratory in Washington, D.C., and now at CU as a faculty member. His publications include theoretical research on equilibria and stability of intense charged particle beams, and experimental research on the physics and applications of both electron and ion beams. He has taught courses in intense charged particle beams at the University of Maryland in 1973, and at CU in 1979 and 1981.*

Atomic and Molecular Physics in Controlled Thermonuclear Fusion

Editors	C. J. Joachain and D. E. Post
Publisher	Plenum Publishing Company
Pages	559
Price	$79.50
Reviewer	C. F. Barnett

Since the beginning of magnetically confined controlled thermonuclear research in 1952-1953, atomic physics processes have played an important role in the heating, energy loss, modeling, and diagnostics studies of high-temperature, low-density (10^{14}-cm^{-3}) plasmas. At the 1958 Second Geneva Conference on Peaceful Uses of Atomic Energy, Edward Teller warned that impurity ions in the plasma may affect the plasma parameters in a catastrophic manner. Moreover, neutral particles formed by charge-exchange in the plasma would traverse the magnetic confining field and sputter additional impurities from the surrounding walls. Indeed, this was the case with the United Kingdom's ZETA toroidal pinch in which impurity levels as high as 30% were measured in a helium discharge. In the ensuing years, little attention was paid to impurities and atomic physics, until the early 1970s when it was discovered that tungsten and gold from tokamak limiters and walls depressed the electron temperature in the plasma center. These observations initiated a renaissance in atomic physics research related to fusion. During the past decade, a worldwide experimental and theoretical research effort has been under way to provide the fusion community with atomic and molecular data relevant to plasma behavior and diagnostics.

This book contains the *Proceedings of the NATO Advanced Science Institute on Atomic and Molecular Physics of Controlled Thermonuclear Fusion* held at Santa Flavia, Italy, on July 19-30, 1982. A similar NATO institute was held in Gers, France, in August 1979 and the proceedings were published as *Atomic and Molecular Processes in Controlled Thermonuclear Fusion* by M. R. C. McDowell and A. M. Ferendeci. In the Preface, the aim of the Institute was stated to be "to bring together senior researchers and students in both atomic physics and fusion research, to survey atomic and molecular processes in fusion plasmas, and to review recent developments in theoretical and experimental research dealing with these processes." Much of the contents of the present proceedings are a survey of fusion and atomic physics as presented in the previous volume, the notable exception being chapters on inertial confinement. Formal presentations at the Institute were divided into three parts:

1. overview of the principles of magnetic and inertial confinement fusion research
2. theoretical and experimental methods of obtaining relevant atomic data
3. atomic and molecular physics of fusion research devices.

Obviously, only a cursory survey of each of these areas can be presented in a reasonably sized book. The reference listings at the end of each chapter contain an impressive 1222 references, which should provide an excellent tool for the newcomer in the field. However, a large fraction of the references are unavailable in most university or industrial laboratories.

Computation of electron ionization cross sections of positive ions within a factor of 2 is one of the most difficult tasks of atomic collision theory, and until recently few experimental measurements were made with multicharged ions. Modelers and diagnosticians in plasma physics were content to use the semiempirical Lotz formula. Recent work showed that in addition to direct ionization, one must also include inner shell excitation followed by autoionization and recombination into doubly excited states followed by Auger emission of two electrons. In these proceedings, the theory as of 1982 was briefly reviewed by McDowell and the experimental status by Dolder and Drawin. Comparison of theory and experimental measurements of Ti^{3+} indicates that the contribution of autoionization is a factor of 5 to 10 greater than that for direct ionization. Measurements with other ions suggest that the relative contribution of the autoionization processes increases with the ion charge and with some light ions the contribution is small. Most of the ionization cross-section data are obtained using crossed beam techniques. Another method used for higher charge states is to measure the reaction rate coefficient in a high-temperature plasma and compare the results to the crossed beam data integrated over a Maxwellian electron velocity distribution. These proceedings did not discuss this technique, which may be the only method in which data for very highly charged states (i.e., Fe^{20+}) can be obtained. At the present time, theory is only capable of reliably predicting ionization cross sections within a factor of 2. The complications introduced by inner shell phenomena in the ionization cross section may also influence the electron excitation cross section of multicharged positive ions.

Also of importance to the understanding of high-temperature plasma behavior is dielectronic recombination collisions, which are difficult to calculate and measure. In this process an incoming electron directly excites an orbital electron and is simultaneously captured into an excited state. Thus, a doubly excited state of the ion is created that is stabilized by the spontaneous emission of a photon. The importance of this process lies in the fact that not only is energy radiated from the confining volume but the average charge state decreases, implying the need of additional energy to heat the plasma to the desired temperature. Throughout the written proceedings, the only place that dielectronic recombination is discussed is a three-page description by Drawin. In all probability dielectronic recombination was discussed at great length during the course, but does not appear in the scientific program.

During the past three to five years, increased emphasis has been placed on the atomic physics in the plasma periphery of tokamak plasmas where the ion and electron temperatures are typically 50 to 500 eV. Diagnostic measurements have shown that many of the central plasma