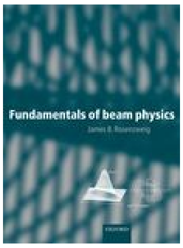

Fundamentals of Beam Physics

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END MATTER

Appendix B: Advanced topics addressed in volume II

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The second volume in this set of texts on beam physics is tentatively entitled "Collective Effects in Intense Beams." It will emphasize the basic physical processes that lay on the frontier in beam physics, which arise when the collective effects associated with the charge and current density of the beams themselves become equal in importance to effects due to the applied fields that were introduced in this volume. The subjects to be addressed in this second volume are more physically complex, and will be therefore treated at a higher level; the result will be appropriate for use as a graduate text, and as a professional reference.

Collective effects have historically been important in circular accelerators, as even relatively small perturbations due to the self-induced forces generated by circulating beams can, in an environment where the beam circulates for long times, eventually produce noticeable effects. Such effects have been studied in depth, with useful references and texts already in existence that summarize the present state of knowledge in these areas. Recent trends in the accelerator physics world, however, are moving toward very intense beams needed for advanced applications that primarily utilize linear accelerators—high-gain free-electron lasers, single-pass linear colliders, heavy ion fusion. Thus, the emphasis has shifted towards addressing extremely strong self-induced forces that can directly and immediately affect the dynamics of the beam. These types of systems are said to display collective beam dynamics.

In the volume following this text, we will examine the effects of such forces, whose common characteristic may be stated as continuous action on the beam itself, due to strong coupling of the beam to its immediate environment. In order to study such systems, one must first examine the fundamental forces and general dynamical responses involved in the processes. They can be due to either collective "static" or radiative fields, and depend on both the beam itself, and the response of the electromagnetic systems the beam comes in contact with. Examples include:

- space-charge fields leading to plasma behavior in beams;
- synchrotron radiation in bending and undulator magnets; energy exchange between a beam with its self-generated radiation field;
- the beam-plasma interaction; linear and nonlinear wake-field excitations;
- the beam-beam interaction in linear colliders, a relativistic "two-stream" system;

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- ↳ beam-matter interaction: scattering, bremstrahlung and Cerenkov radiation, transition radiation at metallic surfaces;
- electromagnetic radiation from nearby boundaries; electromagnetic wake-fields, diffraction radiation, resistive effects.

We note that all of the effects listed above are collective (with the exception of scattering and bremstrahlung), in the sense that the beam-induced fields are macroscopic and coherent—they produce observable effects that depend on the macroscopic beam distribution, not simply on the *incoherent* fields due to individual particles. Such coherent effects include energy exchange (e.g. radiative energy loss) that depends not on the number of particles in the beam, but on the square of this number.

Once we have established a basic understanding of the relevant, fundamental collective processes, a number of phenomena specific to advanced laboratory topics can be investigated:

- space-charge-dominated beam physics: tune shifts, longitudinal and transverse plasma oscillations, emittance growth and compensation;
- ion trapping effects due to space-charge;
- the ultra-high-gain, single-pass free-electron laser, and other radiation-mediated instabilities;
- wake-field accelerators based on metallic structures and dielectrics;
- plasma wake-field acceleration; plasma focusing and self-consistent flows;
- beam-beam disruption, "beamstrahlung," and luminosity enhancement;
- fast longitudinal and transverse instabilities;
- coherent radiation production for diagnosis of ultra-fast beam phenomena.

These topics form a wide survey of coherent effects in state-of-the-art laboratory beams. They illuminate the importance of the general processes discussed, by providing clear examples of their impact on physical systems in actual application. It is, therefore, hoped that this text will provide a broad introduction, as well as a useful reference guide, to many of the fascinating high-intensity beam-based phenomena that make the field of beam physics so active at this time.