Lectures on the Physics of Free Electrons

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Tentative Lecture Contents

As part of the joint agreement between the University of Hawaii (UH) at Manoa and the Brazilian Center for Physics Research (CBPF) a series of lectures will be presented dealing with the classical physics of free electrons and their interaction with EM fields. A particular emphasis will be given to those interaction of relativistic electrons beams in vacuum with periodic EM fields that give rise to the generation and/or amplification of intense coherent electromagnetic radiation in regions of the EM spectrum ($f > 1$ THz) where the power generated by conventional vacuum tube technology is small. This EM spectral region is the one where free electron lasers operate well.

The main purpose of these lectures is to present a series of lectures dealing with the basic theory:(1) of the generation, acceleration and transport of relativistic electron beams and (2) of the generation of intense coherent radiation via the free-electron laser interaction mechanism. The following is a brief summary of the content of these lectures.

Lecture 1: Review of Maxwell's Equations. These equations provides the connection between electric sources and their EM fields. Static solutions will be used to generate fields that can be used to transport, and for certain electron devices, accelerate electron beams. Time dependent solutions of Maxwell's equations will be presented in connection with coherent electron radiation in periodic EM structures.

Lecture 2: Review of discontinuous functions. These functions are useful in describing ideal discontinuous distribution of charges and currents ("point sources") in 1, 2, 3 and 4 dimensions. they are also useful in describing compactly and precisely the spatial and temporal extent of solutions of Maxwell's equations. Review of Fourier Series and Integrals.

Lecture 3: Static magnetic and electric fields. Some solutions of the static Maxwell equations will be used to describe devices employed in bending, focussing and accelerating charged particles and beams.

Lecture 4: Relativistic electron dynamics. The Lorentz force is used with the relativistic form of Newton's laws of motion to find the motion of charged particles and charged beams in the presence of EM fields. The exact motion of charges in an electron beam is obtained by solving in self consistent manner Maxwell's equations and Newton's Laws of motion. One of the most useful approaches to study the motion of charges under the influence of EM fields is through the use of relativistic Hamiltonian theory.

Lecture 5: Velocity modulation. The interaction of waves with charge particles can result in a velocity modulation of an electron beam. With suitable dispersive devices the velocity modulated beam can produce a bunched distribution of charge that is suitable for generating intense electromagnetic waves in devices such as the klystron tube, travelling wave amplifier and the free-electron laser. A bunched electron beam is also required at the input of radio frequency accelerators.

Lecture 6: Electrostatic accelerators. Electrostatic accelerators (V < 30 MV) are ideally suited to accelerate monochromatic, quasi continuous, high brightness charged particle beams. The THz FEL that will soon be installed at the CBPF is driven by 1.7 MV electrostatic accelerator. A discussion will be presented of the major features of the accelerator including a basic description of the charge recovery system.

Lecture 7: Magnetic undulator spontaneous radiation. Solutions of the inhomogeneous Maxwell equations in unbounded space. Lienard-Wiechert fields. Angular and spectral distribution of radiation. Solution of the inhomogeneous Maxwell equations in a parallel plate waveguide. Spontaneous radiation in a parallel plate waveguide.

Lecture 8: Stimulated emission of radiation. One dimensional analysis of a free-electron laser. In addition to spontaneous radiation an electron beam moving through a periodic magnetic structure can amplify a co propagating input high frequency wave. This interaction (stimulated emission of radiation) is described classically as the work done by an electron beam on the input wave. The basic physics of this interaction will be reviewed. Parallel plate waveguide FEL. The FEL interaction region of the CBPF FEL is bounded by parallel conducting plates. The EM radiation generated couples to TE_n modes in the direction perpendicular to the plates and to Hermite-Gaussian modes in the direction parallel to the plates.

Lecture 9: 1D EM radiation and amplification fields via Lienard-Wiechert (LW) fields. The performance of an FEL is usually studied by solving simultaneously Newton's laws of motion and a wave equation. In most cases this is don numerically. A second approach is to use the LW fields, which are the solution of Maxwell's equations for a point electron, together with Newton's laws of motion. A simple 1D analysis of this approach will be presented.