Introduction and Prerequisites

First Chapter

August 24, 2004

What is Accelerator Physics?

- The acceleration of charged particles to high energies has become an important activity with numerous applications:
  - High energy and nuclear physics
  - Material science
  - Isotope production
  - Cancer treatment
  - Fusion
- The physical properties of the beam produced depend on the requirements of its intended application:
  - Particle species, energy, polarization
  - Beam size, intensity, time structure, lifetime
- *Accelerator physics is the field that deals with all the physics issues associated with the production of energetic particle beams.*

Accelerator Systems

- Particle Sources
- Vacuum
- Power Supplies
- Cryogenic Systems
- Accelerating Structure
  - While accelerator R&D covers a broad range of scientific fields and technologies, this course will concentrate on issues and phenomena involving the acceleration and propagation of particle beams through the accelerating structure. As such, this subject is often called beam physics or the physics of beams.

Physics Prerequisites

- Newton's laws: $$\vec{F} = \frac{d\vec{p}}{dt}$$
- Lagrangian and Hamiltonian formulations:

$$H = H(q, p, t) \qquad \frac{dp}{dt} = -\frac{\partial H}{\partial q} \qquad \frac{dq}{dt} = \frac{\partial H}{\partial p}$$

- Harmonic oscillators and their generalizations:

$$\ddot{x} + K(t)x = f(x, t)$$

Physics Prerequisites

- Special relativity: Lorentz transformations, etc.

$$E = \gamma mc^2 \qquad p = \gamma mv \qquad \gamma = \frac{1}{\sqrt{1-\beta^2}} \qquad \beta = \frac{v}{c}$$

- Maxwell's Equations.

$$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0} \qquad \nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{B} = \mu_0 \vec{j} + \frac{1}{c^2}\frac{\partial \vec{E}}{\partial t} \qquad \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

What Subjects Will We Cover?

- Single Particle Motion
  - Longitudinal Motion and Acceleration
  - Transverse Motion in Increasing Detail
    - Linear Approximation
    - Nonlinear Resonances
    - Coupled Motion
- Collective Effects
  - Space Charge
  - Negative Mass Instability
  - Wakefields and Impedances
  - Instabilities
  - Vlasov Equation and Landau Damping
- Emittance Preservation
  - Mismatch
  - Diffusion
  - Cooling
- Synchrotron Radiation
  - Damping
  - Quantum fluctuations and Equilibrium
- Other Topics as Time Permits

Accelerator Physics Resources: Books and Websites

- Basic Texts
  - D.A. Edwards and M.J. Syphers, *An Introduction to the Physics of High Energy Accelerators*
  - H. Wiedemann, *Particle Accelerator Physics*, 2 Volumes
  - S.Y. Lee, *Accelerator Physics*
  - *CERN Accelerator School Notes*, Various subjects
- Handbook
  - A. Chao and M. Tigner, *Handbook of Accelerator Physics and Engineering*
- Beam Optics
  - D.C. Carey, *The Optics of Charged Particle Beams*
- Linear Accelerators
  - T. Wangler, *RF Linear Accelerators*
- RF Superconductivity
  - H. Padamsee, J. Knobloch, and T. Hays, *RF Superconductivity for Accelerators*

Accelerator Physics Resources: Books and Websites

- Collective Dynamics and Instabilities
  - A. Chao, *Physics of Collective Beam Instabilities in High Energy Accelerators*
  - M. Reiser, *Theory and Design of Charged Particle Beams*
  - N.S. Dikansky and D.V. Pestrikov, *The Physics of Intense Beams and Storage Rings*
- Websites
  - Journals
    - http://prst-ab.aps.org/
    - http://pre.aps.org/
  - Conferences
    - http://www-conf.slac.stanford.edu/pac03/, PAC 2003
    - http://www.epac04.ch/index.html, EPAC 2004
  - SNS
    - http://www.sns.gov//
    - http://www.sns.gov//APGroup/APGroup.html

Luminosity:
Need Colliders to Attain High Energy

- For extreme high energy experiments
  - With fixed target, available reaction energy ~ $\sqrt{\gamma}$
  - For colliding beams, available reaction energy ~ γ
  - At very high energies ($\gamma >> 1$) this makes a big difference.
- With fixed target, a tenuous beam strikes a dense target → lots of collisions (events).
- In a collider, a tenuous beam strikes another tenuous beam → few collisions (events). This motivates the push for high luminosity beams.
- So, what is luminosity? It's the quantity relevant to accelerator physics:
  - Reaction Rate = $R = f\,\frac{N^2}{A}\sigma_{\text{int}}$
  - Luminosity = $L = \frac{R}{\sigma_{\text{int}}} = f\,\frac{N^2}{A}$

Brightness: Making Strong Light Sources

- Charged particles emit synchrotron radiation when their paths are bent. Because electrons are so light, they are easily bent, and emit radiation readily. This makes high energy circular electron machines impossible.
- However, it also leads to one of the important machines for studying materials: the synchrotron light source.
- Special undulator magnets are used to shake the electrons, producing well defined high intensity line spectra.
- The figure of merit for accelerator physics is the brightness, defined as

$$B = Max(\frac{d^4F}{dAd\Omega})$$

- The units of brightness are photons / (area × solid angle × time).

Homework:
Assignment due Tuesday, 08/31/2004

- Read Edwards and Syphers, Chapter 1.

- Problems, due Tuesday, 08/31/2004:
  - 1.3
  - 1.6
  - 1.11
  - 1.12
  - 1.15
  - 1.17