Homework Set #6
(due: Wednesday, February 19, 2003)

1. As discussed in the class, we have beam-beam tune shift (due to collision)

$$(\Delta\nu)_{bb} = \pm \frac{N}{4\pi} \frac{r_0}{\varepsilon_N} \Big/ \text{crossing}$$

where N is the # of particles in the opposing beam
r_0 = classical radius of the particle in consideration
ε_N = normalized emittance = $\gamma\varepsilon_x$

Also the incoherent tune shift on particles due to the space charge effect of other particles in the same beam:

$$(\Delta\nu)_{inc} = \frac{-1}{4\pi} \frac{r_0}{\gamma^2 \varepsilon_N} \left(\frac{dN}{ds}\right) \cdot C$$

Here $\frac{dN}{ds}$: line density
C: circumference
γ: relativistic γ

a. Why is the sign of $(\Delta\nu)_{inc}$ negative?

b. Compute beam-beam tune shift for p in Tevatron ($p\bar{p}$ collision).

$\varepsilon_N = 5 \times 10^{-6}$ m-rad
$N_{\bar{p}} = 2 \times 10^{10}$, $N_p = 2 \times 10^{11}$

c. Compute incoherent tuneshift for electrons in Tesla damping ring (electron).

$\varepsilon_N = 1 \times 10^{-5}$ m-rad
c = 17 km
σ_z (rms bunch length) = 6 mm
Energy = 5 GeV

2. A 100-m circumference storage ring is made up of 20 F0D0 cells with a phase advance of 60° per half cell. There are thin dipoles midway between the quadrupoles. Neglect the focusing in the dipoles. You can treat the quadrupoles as thin lenses.

   a. What are the quadrupole strengths (f) and the horizontal and vertical tunes?
   b. Sketch the β-functions and η for one cell.
   c. The dipoles have random strength errors with an rms of $\sigma = 0.01\%$. What is the rms closed-orbit error at one of the horizontally focusing quadrupoles?
   d. The quadrupoles have random focusing errors with an rms of $\sigma = 0.05\%$. What is the rms spread in tunes and the rms error in the β-functions?

3. Continue working with the storage ring in problem 2.

   a. What are the horizontal and vertical chromaticities?
   b. Sextupoles are placed at the quadrupole locations to make these chromaticities equal to zero. What are the required sextupole strengths?