Homework Problems I
Accelerator Physics

1. Evaluate the rest energy (in MeV) for the proton ($m_p = 1.673 \times 10^{-27}$ kg) and the deuteron ($m_d = 1.673 \times 10^{-27}$ kg). Next, assume $\gamma = 2$ for either particle. What is the particle velocity (m/sec)? What are the "kinetic energies" (the total energy minus the rest energy) for both particles in MeV. Repeat for $\gamma = 10$.

2. Calculate the non-relativistic cyclotron angular frequency and cyclotron frequency of the proton and the deutreron in a 0.3 T magnetic field.

3. Suppose a particle orbit as a function of time $\vec{x}(t)$ is given in an inertial frame *K* and the integral

$$\tau = \int_{t_1}^{t_2} \frac{dt}{\gamma(t)} = \int_{t_1}^{t_2} \sqrt{1 - \beta_x^2(t) - \beta_y^2(t) - \beta_z^2(t)}\, dt$$

is evaluated. Using the invariance of the space-time interval, show that if the same calculation is done in a frame *K'* moving uniformly with respect to *K*, then $\tau' = \tau$. In other words, the proper time τ along a particle orbit is a Lorentz invariant quantity.

4. The so-called East Arcs in the CEBAF electron accelerator at Jefferson Lab consist of five separate beam-lines that operate at different electron beam energies. The rectangular dipoles in each beam-line are identical and all together bend the beam through 180 degrees. More and longer magnets are needed to bend the higher beam energy electrons. When the total electron energy is 5500 MeV, the electron energy in each of the arcs is given in the table. With the information given, calculate the other entries in this table:

Arc	Electron Energy (MeV)	Number of Dipoles	Dipole Length (m)	Bend Angle (rad)	Magnetic Field (T)
1	605	16	1		
2	1693	32	1		
3	2781	32	2		
4	3868	32	3		
5	4956	32	3		

5. Using Mandelstam Variables s, t, u in lecture 1 slide 13 show that

$$s + t + u = (m_1^2 + m_2^2 + m_3^2 + m_4^2)c^2$$