You can answer in English or in Finnish. Voit vastata englanniksi tai suomeksi.

1. The average magnetic field at outer radius (extraction) of a cyclotron is 1.76 T and extraction radius is 94 cm. The flutter at extraction is 0.04. What must the spiral angle be (at least) if you want to accelerate 90 MeV protons?

2. A focusing doublet consists of two short lenses with a drift space between them. The focal length of the first lens is f_1 (>0) and the focal length of the second lens is f_2 (<0). The distance between the lenses is d. Calculate the transverse transfer matrix for the system.
   Give a condition to the focal lengths so that the doublet is effectively focusing.

3. Compare the operation of a synchrocyclotron and an isochronous cyclotron.

4. The geometrical emittance of a 20 keV proton beam is 100π mm mrad. Calculate the normalized emittance.

5. Derive the Kerst-Serber equations that give the focusing condition for a cylindrically symmetric magnetic field.

6. Which of the following transfer matrices can be a transfer matrix/matrices of a working synchrotron (or cyclotron at fixed energy)? Explain why!

   a) $\begin{pmatrix} -0.4 & 4.0 \\ -0.19 & -0.6 \end{pmatrix}$

   b) $\begin{pmatrix} 0.3 & 0.8 \\ -4.0 & 0.4 \end{pmatrix}$

   c) $\begin{pmatrix} -1.2 & 0.4 \\ -1.0 & -0.5 \end{pmatrix}$

   d) $\begin{pmatrix} 1.3 & -0.045 \\ 2.0 & 0.7 \end{pmatrix}$

Atomic mass unit u	1.66054×10^{-27} kg
Proton mass	1.007 u
Electron mass	5.4858×10^{-4} u
Unit charge	1.6022×10^{-19} C
Speed of light	2.99792458×10^{8} m/s