Karlsruhe Institute of Technology

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Accelerator Physics WS24/25

Exercise sheet 1 (Submission: 12.11.2024)

Exercise 1: linear accelerator (2 points)

When linear accelerators were still in their infancy, technical limitations restricted the frequencies of the accelerating alternating currents to about 50 kHz. As a result, initially, only heavy ions could be accelerated. Once higher frequencies became technically feasible, lighter particles could also be efficiently accelerated (protons at 200 MHz and electrons at 3 GHz).

Why are higher frequencies used for lighter particles to achieve the same final energies?

Exercise 2: Betatron (3 points)

In a Betatron, electrons can be accelerated to up to 300 MeV.

(a) What magnetic flux density at the orbit (orbit radius = 1 m) and what average magnetic flux density must prevail when the electrons have reached 300 MeV. (2)
Tip: Consider Wideröe's Betatron condition: $B(t) = \frac{1}{2}\langle B(t)\rangle + B_0$, where B_0 can be neglected in this case.

(b) Iron saturates at about 2 T, how do you assess the feasibility of a 10 GeV Betatron? (1)

Exercise 3: Cyclotron (3 points)

On January 2, 1931, M. S. Livingston and E. Lawrence demonstrated the cyclotron principle in Berkeley, California. They successfully accelerated "hydrogen ions"(protons) in a cyclotron with a diameter of 4.5 inches (11.43 cm) to a kinetic energy of 80 keV. The high-frequency alternating voltage provided a potential difference of 1.8 kV in the acceleration gap.

(a) Calculate the magnetic flux density (B) in this cyclotron. (1)

(b) How many orbits do the protons complete before reaching this energy, and what is the minimum frequency the high voltage must have for the particles to pass through the acceleration gaps at the right time? (1)
(Tip: Consider the energy gain when passing through the acceleration gap.)

(c) What kind of problems arise for highly relativistic particles?
How could one counteract these problems? (1)

Exercise 4: Microtron (3 points)

In the KARA microtron, electrons are accelerated from 70 keV to 53 MeV in 10 orbits. The microtron's linac is fed with 3 GHz, and the orbit length increases by one RF wavelength per orbit. Right after the electrons enter the microtron from the gun, they pass through the acceleration section for the first time. Following a subsequent 180° rotation, they pass through the linac again before completing the remaining 8 orbits.

After the first pass through the linac, the electron's velocity can be approximated as nearly the speed of light ($v \approx c$).

(a) Calculate the maximum orbit radius. (2)

(b) What problem arises when the microtron is operated with non-relativistic particles? (1)