Problem Set 1 – Introduction to Accelerator Physics

Each problem gives you a letter. If you have solved all the problems correctly the letters can be combined into an accelerator related word. Find the word.

Problem 1

a) How much faster is an electron with kinetic energy 5 MeV than an electron with kinetic energy 2 MeV? And for protons?
b) If you accelerate an electron and a proton, which one of them is easier to get to relativistic velocities?

Problem 2

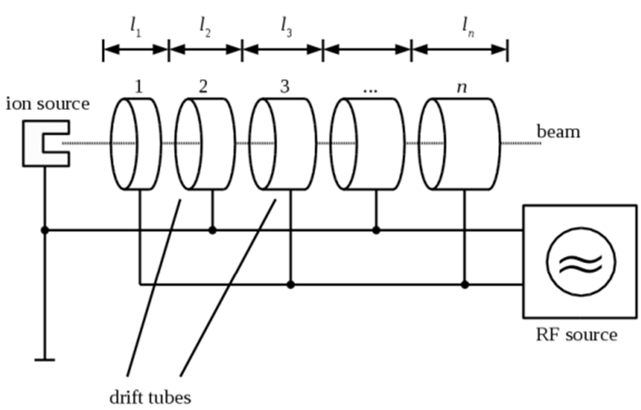
We want to control the motion of a charged particle with electric and magnetic fields. Which type of field/s can we use to increase the energy of the particle? And which type of field/s can we use to change the direction of the particle?

Problem 3

a) Using the Lorentz force and the centripetal force, what is the angular revolution frequency of a cyclotron? What happens to the revolution frequency as the particles become relativistic?
b) A microtron is a type of cyclotron for electrons where the energy gain per revolution is tuned so that the revolution period always increases by an integer of the RF period. Then the electron sees the same phase each revolution despite the revolution period not being constant. What is the energy gain per revolution for a circular microtron?
c) What is the radius of a microtron with maximum energy 25 MeV and $B = 1.2$ T?

Problem 4

What is the length of the 1st and 5th drift section in a Widerøe linear accelerator with $f_{RF} = 7$ MHz, energy gain in the gap 1 MeV and starting kinetic energy of 100 keV? Calculate for protons and electrons. Assume the accelerating gaps to be very short compared to the drift tubes.



Problem 5

A dipole magnet has a 1-turn coil with 400 A.

a) How large should the gap be to produce 0.1 T?
b) How large is the power consumption if you use a copper wire (1 m long) with an area of 5 mm^2 and resistivity of $1.7 \cdot 10^{-2}$ Ω mm^2/m? Change to a 20 turn coil using 20 times longer wire. Does the power decrease or increase?

Problem 6

The MAX IV 1.5 GeV is 96 m in circumference and has 24 dipole magnets. What is the bending angle of the dipoles? If each magnet is 1 m long, which bending radius does this correspond to? What is then the field strength of a dipole?

Problem 7

The MAX IV 3 GeV ring has the following parameters:

Circumference	528 m
RF frequency	100 MHz
Current	500 mA

How many bunches is there in the ring if all buckets are filled? How much charge is there in one bunch?

The word is ____________________________

Extra problem

The MAX IV 3 GeV storage ring is a world-leading synchrotron light source. This is due to it having a multibend achromat (MBA) lattice. Try to find the following information online:

a) What is an MBA lattice?
b) Which property of an accelerator does the MBA lattice improve?
c) Why is this of importance for a synchrotron light source?

Key

Problem 1

a) For electrons 3.6% and for protons 35.9% faster → P
For electrons 78.4% and for protons 1.3% faster → E
For electrons 1.7% and for protons 57.8% faster → N

b) The electron → R
The proton → Y
Both is equally easy → I

Problem 2

Both electric and magnetic fields can be used to increase the energy and change the direction of the particle → F

Both electric and magnetic field can be used to change the energy of the particle, whereas only electric field can be used to change the direction → A

Electric fields can be used to change the energy of the particle, whereas both electric and magnetic field can be used to change the direction → R

Problem 3

a) $\omega = \frac{qB}{m}$ → C
$\omega = \frac{qm}{B}$ → L
$\omega = \frac{Bm}{q}$ → O

b) $\Delta E = k\frac{\omega_{RF}}{qc^2B}$ → I
$\Delta E = k\frac{qc^2B}{\omega_{RF}}$ → H
$\Delta E = kc^2B\omega_{RF}$ → Y

c) The radius is 2.5 m → S
The radius is 0.07 m → N
The radius is 0.04 m → A

Problem 4

For protons we have $l_1 = 5.27$ m and $l_5 = 30.4$ m
and for electrons $l_1 = 1.3$ m and $l_5 = 5.4$ m → K

For protons we have $l_1 = 1.04$ m and $l_5 = 2.24$ m
and for electrons $l_1 = 20.3$ m and $l_5 = 21.3$ m → O

For protons we have $l_1 = 6.7$ m and $l_5 = 2.67$ m
and for electrons $l_1 = 90.4$ m and $l_5 = 15.4$ m → V

Problem 5

a) The gap should be 10.7 mm → E
   The gap should be 1.6 mm → B
   The gap should be 5.06 mm → T

b) The power consumption is 544 W and decreases with more turns → S
   The power consumption is 25.3 W and increases with more turns → U

c) The power consumption is 487 W and decreases with more turns → I

Problem 6

The bending angle is 10°, the bending radius 15.28 m and the magnetic field 2.53 T → C

The bending angle is 17.6°, the bending radius 1.752 m and the magnetic field 5.26 T → E

The bending angle is 15°, the bending radius 3.820 m and the magnetic field 1.31 T → Y

Problem 7

There are 176 bunches and 5 nC per bunch → O

There are 880 bunches and 1 nC per bunch → U

There are 549 bunches and 1.6 nC per bunch → L