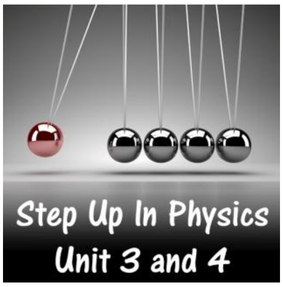
Particle Accelerators

Problems Worksheet



1. A linear accelerator is comprised of several components that work towards increasing the velocity of subatomic particles or ions. Describe the function of the following components.
   a. Drift tube

   b. Radiofrequency power source

   c. Vacuum chamber

   d. Ion source

2. The drift tubes in linear accelerators are broken into segments and each of these segments get progressively longer towards the target.
   a. Explain why the drift tubes are broken into segments.

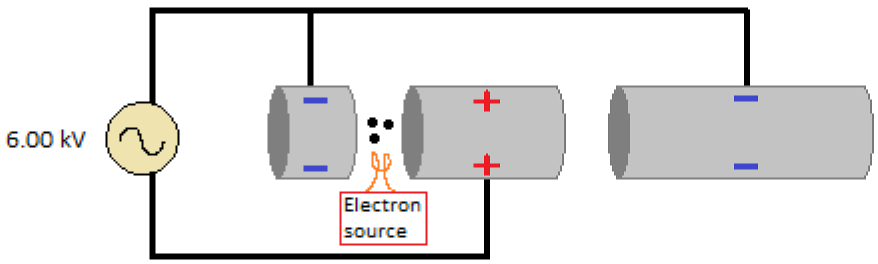
   b. Explain why the drift tubes get progressively longer.

3. A 50.0 GeV linac is 3.20 km long and is designed to work with protons in the beamline. The protons gain 50.0 GeV of kinetic energy within the linac.
    a. Using the classical formula for kinetic energy, calculate the velocity of the protons that exit the linac.

    b. Describe why relativistic effects need to be considered to determine the velocity of the protons that exit this linac.

    c. Including relativistic effects, calculate the velocity of the protons that exit the linac. Give your answer with 5 significant figures.

4. In the linear accelerator below, electrons are injected between the first two drift tubes and may be considered to initially be at rest. They are accelerated by a 6.00 kV potential across the two drift tubes. The speed the electrons reach while moving through this potential is not relativistic. The frequency of the RF power source is 1.20×10^7 Hz.
    a. How long should the middle drift tube be so that the electrons experience further acceleration when reaching the end of the middle drift tube?



b. An undergraduate physics student suggested that the electron source be replaced with a proton source and the RF power source be reversed to turn the linear accelerator into a proton accelerator. Suggest a reason this would not work.

5. A linear accelerator is capable of accelerating protons from rest up to 0.998 c. Calculate the work done by the linac on the protons.

6. Synchrotrons utilise both electric and magnetic field.
   a. Describe the role of the magnetic field in the synchrotron.

   b. Explain why charged particles slow down without the electric field when stored within the beamline of a synchrotron.

7. Large scale synchrotrons have several stages that each have a specific function. This includes a small booster ring and a larger storage ring.
    a. Apart from the storage ring and booster ring, what is the other main stage of a large scale synchrotron?

    b. Explain why the booster ring requires more powerful electromagnets than the storage ring.

    c. Explain why the booster ring electromagnets need have a variable strength that allows them to start off weak but ramp up to much higher values.

    d. State why the beamline must be within a vacuum.

    e. The beam decays over time because of the loss of beam's particles. Suggest a physical reason why particles would be lost from the beam.

8. The Australian Synchrotron has a 34.4 m radius storage ring that can hold a 3.00 GeV electron beam which results in the electrons moving at 0.99999998541c.
(*Note: if your calculator cannot hold this many significant figures, expect rounding issues with the answer)*
    a. Calculate the mass of the electrons in the storage ring.

    b. Calculate the centripetal force required to maintain the circular path the electrons must follow.

    c. How is the centripetal force produced?

    d. Calculate the average magnetic flux density that would be required to keep the electron beam within the circular storage ring.

9. The Large Hadron Collider (LHC) is the largest synchrotron in the world with a 27.0 km circumference. It also produces the most energetic protons in the world. During early test runs the proton beam operated at 450 GeV.
    a. Calculate the velocity of the high energy protons. Give your answer to 9 significant figures.

b. Calculate the relativistic mass of the high energy protons.

c. Calculate the average magnetic flux density required to keep the high energy protons within the LHC beamline.

d. Suggest a reason why the electromagnets used by the LHC produce a larger magnetic flux density than predicted by your answer to part (c).

e. The latest experiments in the LHC use proton beams of 6.50 TeV. Calculate how much faster (in ms^{-1}) these protons a moving compared to early tests.

f. 6.50 TeV is an order of magnitude higher than 450 GeV. Why does a 10 times increase in energy result in such a small increase in velocity?

g. State the advantage of using larger energies for the proton beams in the LHC.

10. The Higgs boson is a fundamental particle with a 126 GeV/c^2 rest mass. The units GeV/c^2 can be used a unit of mass because of Einstein's mass-energy equivalence ($m = E/c^2$). The Higgs boson was experimentally confirmed in 2012 using the Large Hadron Collider after smashing two proton beams moving in opposite directions into each other.

    a. What is the minimum amount of energy required to produce a Higgs boson?

    b. What is the minimum energy of each beam required to produce a Higgs boson assuming the energy was used 100 % efficiently?

    c. What velocity would the protons have at this energy? Give your answer to 6 significant figures

    d. Why were two beams used on a direct collision course instead of just one aimed at a stationary target?

    e. The actual beam energy was closer to 6.00 TeV. Suggest a reason for using a higher beam energy.

