19 The first cyclotron was created by E O Lawrence in 1931.

Lawrence obtained an expression for the time t for a particle of charge q and mass m to complete a circular path in a uniform magnetic field of magnetic flux density B.

The expression obtained by Lawrence is

$$t = \frac{2\pi m}{Bq}$$

(a) (i) Derive this expression.

(3)

(ii) In Lawrence's cyclotron, an alternating potential difference was used to accelerate particles to high energies.

Explain the significance of the expression obtained by Lawrence to the operation of a cyclotron.

(4)

(b) In a cyclotron, in which Lawrence's expression applies, protons were accelerated to a speed of $1.5 \times 10^7\,m\,s^{-1}$.

Determine the time taken to accelerate a proton to this speed from rest.

magnetic flux density = 1.6 T

accelerating potential difference = 13 kV

(5)

Time = ...

(c) Explain why high energy particles are required to investigate the structure of nucleons.

(3)

(Total for Question 19 = 15 marks)