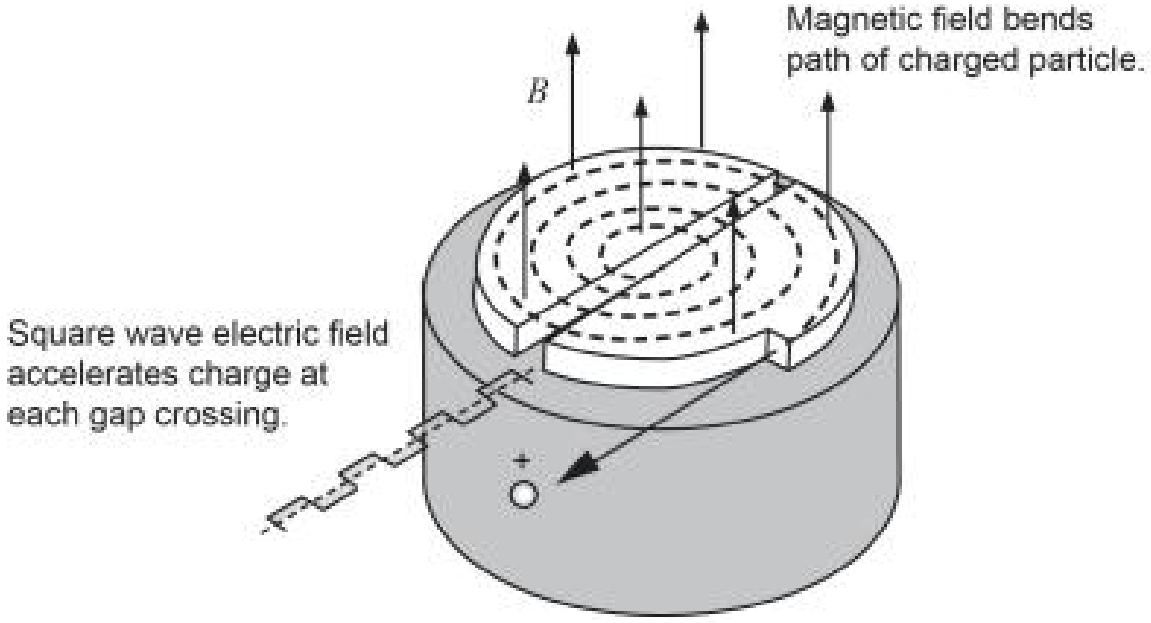
Question 20 **(19 marks)**

Cyclotrons

A cyclotron is a particle accelerator. It is an electrically-powered machine that produces a beam of charged particles that can be used for medical, industrial and research purposes. A cyclotron accelerates charged particles in a spiral path, which allows for a much longer path for acceleration than a straight-line accelerator.

A cyclotron consists of two semicircular charged plates in a flat vacuum chamber called 'dees' because of their shape. The chamber sits between the poles of a magnet that creates a strong and vertical magnetic field. A stream of charged particles is fed into the centre of the chamber and a high-frequency alternating voltage is applied across the plates. This voltage accelerates the charged particles across the gap every half turn. Combined with the magnetic field, this process causes the particles to spiral outwards until they exit the cyclotron.



The cyclotron frequency (how often the electric field between the dees reverses) is independent of both the velocity of the particles and the radius of the circular path they follow.

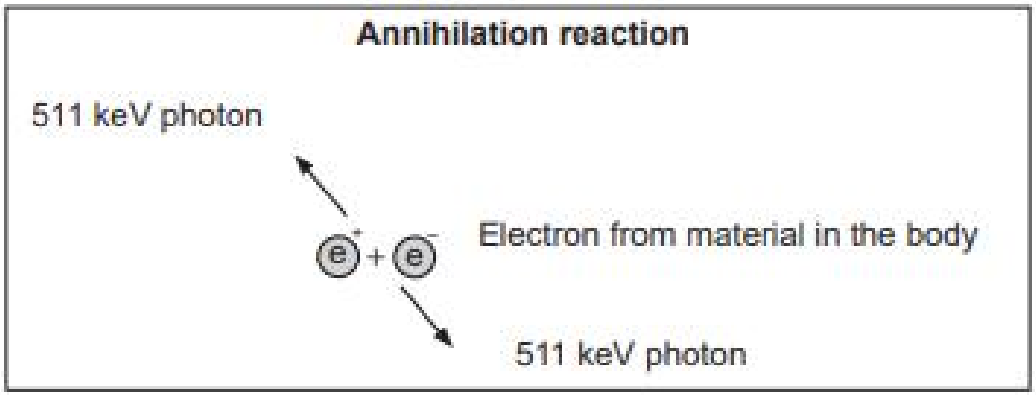
Medical cyclotrons

Medical cyclotrons produce proton beams that are used to manufacture radioisotopes used in medical diagnosis. Radioisotopes produced in a cyclotron decay by either positron emission or electron capture. Positron emission tomography (PET) and single photon emission computed tomography (SPECT), which utilises gamma ray emission, are two imaging techniques that rely on cyclotron-produced radioisotopes.

(a) The diagram above shows the acceleration of a positive particle in a cyclotron. Describe one change that would need to be made in order to use the same machine to produce a beam of negatively-charged particles exiting from the same place, and explain why.

(3 marks)

Positrons (e^+) are examples of antimatter and have the same properties as electrons (e^-) except for having a positive charge. When they collide with an electron, the following process occurs.



(b) (i) Calculate the wavelength of the photons produced in the annihilation described in the diagram above. (3 marks)

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(ii) To which part of the electromagnetic spectrum does the photon belong? (1 mark)

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(c) Explain why increasing the strength of the magnetic field would increase the velocity of the particles leaving the cyclotron. (4 marks)

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(d) (i) Explain why the voltage across the dees must alternate. (2 marks)

On page 31 the text states: 'The cyclotron frequency (how often the electric field between the dees reverses) is independent of both the velocity of the particles and the radius of the circular path they follow.'

(ii) Derive an expression for the cyclotron frequency and use the expression to explain why this statement is correct. (Ignore relativistic effects.) (6 marks)