7 A cyclotron is a device used to accelerate ions to very high speeds. Fig. 7.1 shows a top-view diagram of a cyclotron. It is composed of two hollow, semi-circular electrodes called "Dees". The

"Dees" are encased inside a vacuum chamber and exposed to a perpendicular uniform magnetic field. An ion source lies in between the "Dees" at point A. An alternating voltage supply is connected across the "Dees" such that the voltage changes between $+V$ and $-V$ after a constant time duration.

During operation, the voltage supply produces an alternating electric field in the small gap between the "Dees". This is to ensure that the ions are accelerated each time they cross the gap. On entering the "Dees", the uniform magnetic field causes the ions to move in a circular path. As the ions speed up, they travel in ever larger circles within the "Dees". Once the ions reach a sufficiently large speed, they exit through an outlet in one of the "Dees" which is aimed at a target.

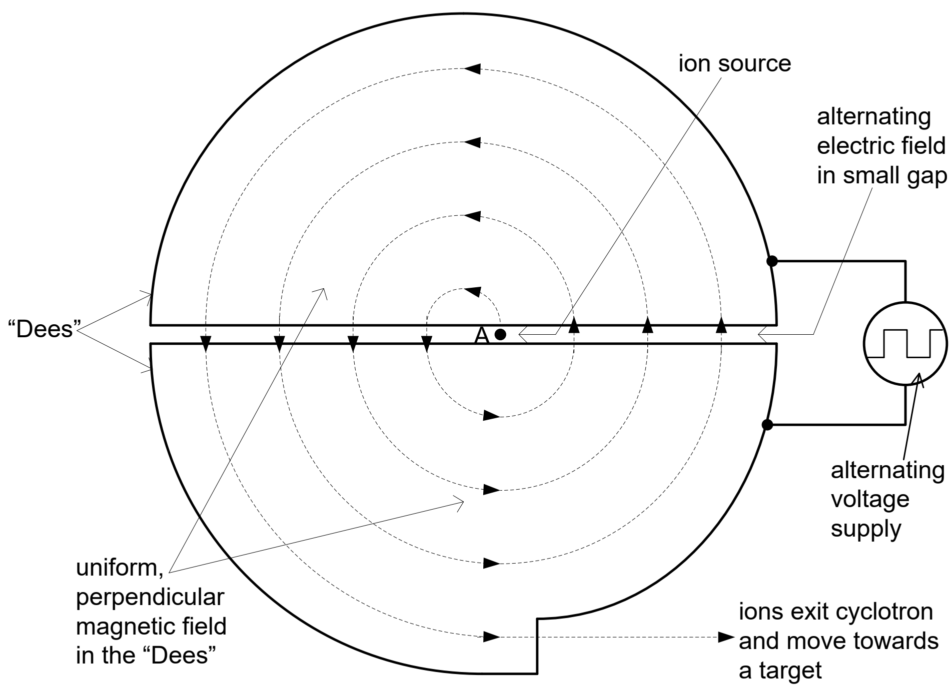

Fig. 7.1

At any time when an ion of mass *m* and charge *q* accelerates across the small gap, the potential difference between the "Dees" is *V*. The ion then travels in a circular path in the "Dees" where a uniform magnetic field of flux density *B* is applied perpendicularly.

(a) Show that the time *T* for the ion to complete one revolution in the cyclotron is independent of the radius of its circular path *r*.

State an assumption you made.

[3]

(b) A helium nucleus of mass 6.68×10^{-27} kg and charge 2*e* (where *e* is the elementary charge) is accelerated in the cyclotron by applying an alternating potential difference of 450 V across the "Dees". The magnetic flux density through the "Dees" is 0.850 T.

(i) Calculate the time *T* to complete one revolution for the helium nucleus.

T = ……………………s [2]

(ii) Determine the frequency f of the alternating voltage supply so that the helium nucleus is accelerated each time it crosses the gap between the "Dees". Explain your answer.

f = ……………………Hz [2]

(iii) Explain why the expression for the gain in kinetic energy of the helium nucleus after one revolution is $4eV$.

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[2]