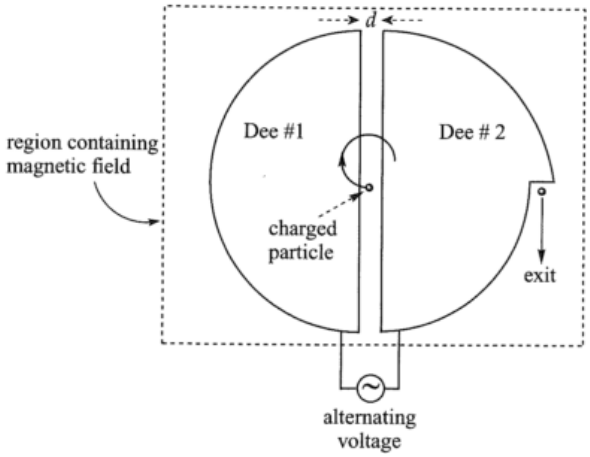
3) A cyclotron is a device used to accelerate charged particles to high speeds. It consists of two hollow containers - called dees because of their shape - facing each other and separated by a small gap. They are immersed in a uniform magnetic field, B, and are attached to a source of alternating voltage. A charged particle is projected from the center of the cyclotron into Dee #1, and the magnetic force causes it to turn in a circle. When it completes its semicircular path within one dee, the polarity of the voltage is reversed, and the particle is accelerated across the gap into the adjacent dee. This process continues, and the particle spiral outward at faster and faster speeds, until it emerges from Dee #2. Notice that the voltage must be alternated twice during each revolution of the particle. The figure below shows view - looking down from above 0 of a cyclotron.

a) explain why the electric field in the gap must be used to increase the speed of the particle.



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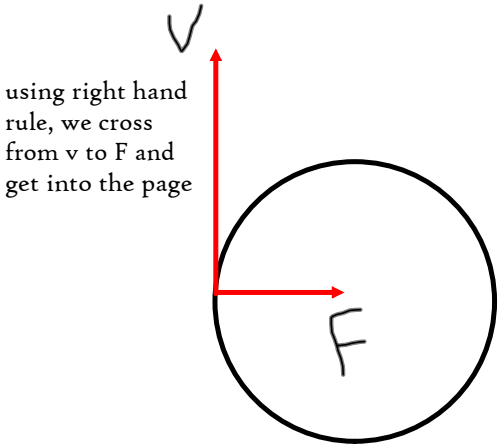
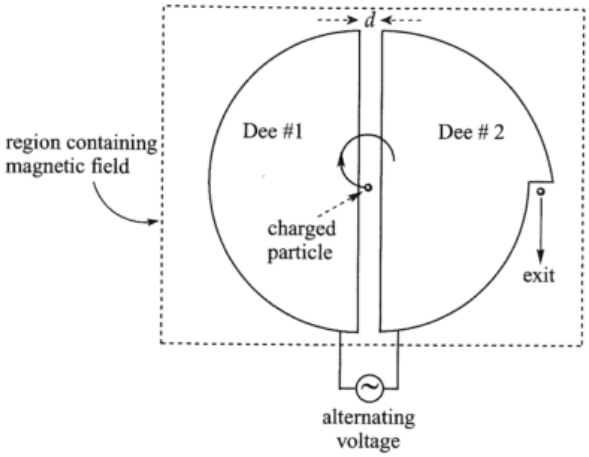
b) Should the magnetic field point into the plane of the page or out of the plane of the page in order to cause the particle to rotate clockwise as shown in the figure?





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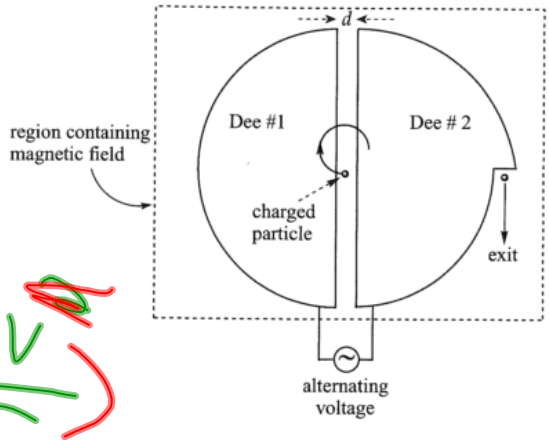
c) Show that the time to complete one revolution does not depend on the speed of the proton, and determine this orbital period.



$$T = \frac{2\pi r}{v}$$

$$qvB = \frac{mv^2}{r}$$

$$\frac{qB}{m} = \frac{v}{R} \rightarrow \frac{m}{qB} = \frac{R}{v}$$

$$T = \frac{2\pi r}{v}$$

$$T = \frac{2\pi m}{qB}$$

e

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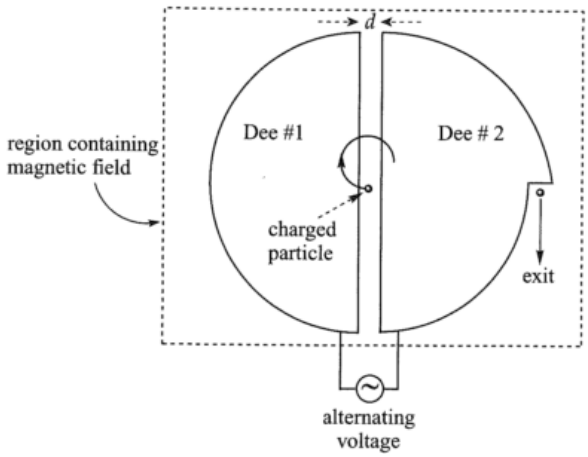
d) How many revolutions does the proton make per second?

$$T = \frac{2\pi m}{eB}$$

$$T^{-1} = \frac{eB}{2\pi m}$$



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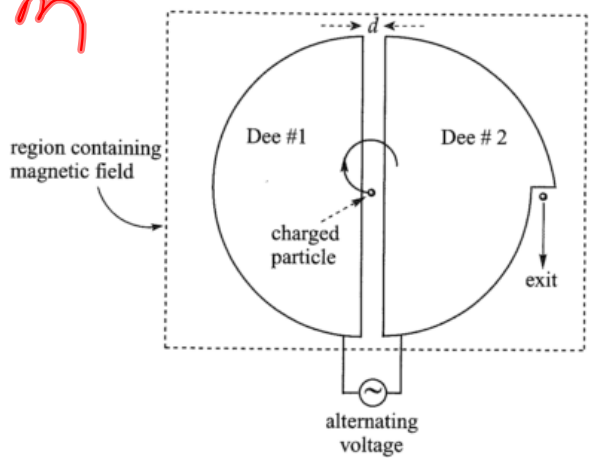
e) What must be the frequency (in Hz) of the alternating voltage?

$$T = \frac{eB}{2\pi m} \qquad T = \frac{eB}{\pi m}$$

$$T = \frac{2eB}{2\pi m}$$



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f) If the maximum radius of the proton's orbit is R, what is its maximum kinetic energy upon exiting? (Your answer should also include R.)

$$evB = \frac{mv^2}{R}$$

$$v = \frac{eBR}{m}$$

$$KE = \frac{1}{2}mv^2$$

$$= \frac{1}{2}m\left(\frac{eBR}{m}\right)^2$$

$$\frac{1}{2}\frac{e^2B^2R^2}{m}$$

$$KE = \frac{e^2B^2R^2}{2m}$$