

(13.7) Calculate the maximum energy (a) for protons, deuterons, and helium ions in a cyclotron, whose maximum orbit diameter is 1.25 m and whose frequency is 12 MHz. (b) What magnetic field strength would be required in each case?

Begin with the usual units and constants:

$$u_n := 1.660540 \cdot 10^{-27} \cdot \text{kg} \quad c_{\text{light}} := 299792458 \cdot \text{m} \cdot \text{sec}^{-1} \quad \text{MeV} := 1.6021773 \cdot 10^{-19+6} \cdot \text{joule}$$

$$q_e := 1.6021773 \cdot 10^{-19} \cdot \text{coul}$$

Data for the cyclotron:

$$f := 12 \cdot \text{MHz} \quad d_{\text{max}} := 1.25 \cdot \text{m} \quad r_{\text{max}} := \frac{d_{\text{max}}}{2}$$

$$v_{\text{proj}} := f \cdot 2 \cdot \pi \cdot r_{\text{max}} \quad v_{\text{proj}} = 4.712 \cdot 10^7 \cdot \text{m} \cdot \text{sec}^{-1}$$

$$\beta := \frac{v_{\text{proj}}}{c_{\text{light}}} \quad \beta = 0.157 \quad f_{\text{rel}} := \frac{1}{\sqrt{1 - \beta^2}}$$

$i := 1 \dots 3$ Do all calculations for the three particles in array mode ($i=1$, p^+ , $i=2$, d^+ , $i=3$, α):

$$M_i :=$$

1.00727947
2.014102 - 0.000549
4.002603 - 2 \cdot 0.000549

p^+ -mass,
 d^+ -mass and
 α -mass in amu

$$z_i :=$$

1
1
2

$$m_i := M_i \cdot u_n \cdot f_{\text{rel}}$$

$$E_i := M_i \cdot u_n \cdot (f_{\text{rel}} - 1) \cdot c_{\text{light}}^2$$

$$B_i := \frac{\sqrt{E_i \cdot 2 \cdot m_i}}{z_i \cdot q_e \cdot r_{\text{max}}}$$

$$E_i$$

$1.892 \cdot 10^{-12} \cdot \text{kg} \cdot \text{m}^2 \cdot \text{sec}^{-2}$
$3.783 \cdot 10^{-12} \cdot \text{kg} \cdot \text{m}^2 \cdot \text{sec}^{-2}$
$7.517 \cdot 10^{-12} \cdot \text{kg} \cdot \text{m}^2 \cdot \text{sec}^{-2}$

$$B_i$$

$0.8 \cdot \text{kg} \cdot \text{sec}^{-1} \cdot \text{coul}^{-1}$
$1.598 \cdot \text{kg} \cdot \text{sec}^{-1} \cdot \text{coul}^{-1}$
$1.588 \cdot \text{kg} \cdot \text{sec}^{-1} \cdot \text{coul}^{-1}$

OBS ! $1 \cdot \text{MeV} = 1.602 \cdot 10^{-13} \cdot \text{kg} \cdot \text{m}^2 \cdot \text{sec}^{-2}$

$$Ee_i := \frac{E_i}{\text{MeV}}$$

$$Ee_i$$

11.811	MeV
23.61	MeV
46.92	MeV