Inhereted velocity of the particles

⇒ Each particle that has separated from the compound nucleus has an inhereted velocity ($\vec{V}_{inh}$) equal to the velocity of the compound nucleus ($\vec{V}_{CN}$).

I. Inhereted velocity of the helium-4 nucleus :–

$$V_{inh} = V_{CN} = 1.1538 \times 10^7 \text{ m/s}$$

⇒ Components of the inhereted velocity ($\vec{V}_{inh}$) of helion-4

1. $\vec{V}_x = V_{inh} \cos\alpha = V_{CN} \cos\alpha = -0.9137 \times 10^7$ m/s

2. $\vec{V}_y = V_{inh} \cos\beta = V_{CN} \cos\beta = 0.7047 \times 10^7$ m/s

3. $\vec{V}_z = V_{inh} \cos\gamma = V_{CN} \cos\gamma = 0$ m/s

II. Inhereted velocity of the proton

$$V_{inh} = V_{CN} =$$

⇒ Components of the inhereted velocity ($\vec{V}_{inh}$) of proton

1. $\vec{V}_x = V_{inh} \cos\alpha = V_{CN} \cos\alpha = -0.9137 \times 10^7$ m/s

2. $\vec{V}_y = V_{inh} \cos\beta = V_{CN} \cos\beta = 0.7047 \times 10^7$ m/s

3. $\vec{V}_z = V_{inh} \cos\gamma = V_{CN} \cos\gamma = 0$ m/s

III. Inhereted velocity of the reduced mass (Δm):

$$V_{inh} = V_{CN} =$$

⇔ As the lithion-5 is an unstable homogenous compound nucleus. So, the inhereted velocity ($\vec{V}_{inh}$) of the each separated particle (the helium-4 nucleus, the proton and the reduced mass) is equal to the final velocity ($\vec{V}_f$) of the lithion-5.

Propellation of the particles

1. Reduced mass

$$\Rightarrow \Delta m = [m_{Li-5}] - [m_{He-4} + m_p]$$

$$\Rightarrow \Delta m = [5.0109] - [4.0015 + 1.0072] \text{ amu}$$

$$\Rightarrow \Delta m = [5.0109] - [5.0087] \text{ amu}$$

$$\Rightarrow \Delta m = 0.0022 \text{ amu}$$

$$\Rightarrow \Delta m = 0.0022 \times 1.6605 \times 10^{-27} \text{ Kg}$$
$$= 0.0036531 \times 10^{-27} \text{ Kg}$$

2. Inhereted kinetic energy of reduced mass

$$E_{inh} = \frac{1}{2} \Delta m \, v_{inh}^2 = \frac{1}{2} \Delta m \, v_{CN}^2$$

$$v_{CN}^2 = 1.3099733 \times 10^{14} \, m^2/s^2$$

$$\Rightarrow E_{inh} = \frac{1}{2} \times 0.0036531 \times 10^{-27} \times 1.3099733 \times 10^{14} \text{ J}$$

$$= 0.0014 = 0.002392731 73 \times 10^{-13} \text{ J}$$
$$= 0.001495 \text{ MeV}$$

3. Released energy (E_R) :

$$E_R = \Delta m c^2$$
$$= 0.0022 \times 931 \quad \text{Mev}$$
$$= 2.0482 \quad \text{Mev}$$

4. Total energy (E_T) :

$$E_T = E_{inh} + E_R$$
$$= [0.0014] + [2.0482] \quad \text{Mev}$$
$$= 2.0496 \quad \text{Mev}$$

Increased kinetic energy of the proton

$$E_{inc} = \frac{m_{He-4}}{m_{He-4} + m_p} \times E_T$$

$$= \frac{4.0015}{4.0015 + 1.0072} \times 2.0496 \quad Mev$$

$$= \frac{4.0015}{5.0087} \times 2.0496 \quad Mev$$

$$= 0.7989089677 \times 2.0496 \quad Mev$$

$$= 1.6374 \quad Mev$$

Increased kinetic energy of the helion-4

$$E_{inc} = [\, E_T - \text{Increased kinetic energy of proton} \,]$$

$$= [\, 2.0496 \,] - [\, 1.6374 \,] \quad Mev$$

$$\Rightarrow E_{inc} = 0.4122 \quad Mev$$

Increased velocity (V_{inc}) of the proton

$$V_{inc} = \left[\frac{2E_{inc}}{m_p}\right]^{\frac{1}{2}}$$

$$= \left[\frac{2 \times 1.6374 \times 1.6 \times 10^{-13}}{1.6726 \times 10^{-27}}\right]^{\frac{1}{2}} \text{ m/s}$$

$$= \left[\frac{5.23968 \times 10^{-13}}{1.6726 \times 10^{-27}}\right]^{\frac{1}{2}} \text{ m/s}$$

$$= \left[3.1326557 4554 \times 10^{14}\right]^{\frac{1}{2}} \text{ m/s}$$

$$= 1.7699 \times 10^{7} \text{ m/s}$$

Increased velocity (V_{inc}) of the helion-4

$$V_{inc} = \left[\frac{2E_{inc}}{m_{He-4}}\right]^{\frac{1}{2}}$$

$$= \left[\frac{2 \times 0.4122 \times 1.6 \times 10^{-13}}{6.64449 \times 10^{-27}}\right]^{\frac{1}{2}} \text{ m/s}$$

$$= \left[\frac{1.31904 \times 10^{-13}}{6.64449 \times 10^{-27}}\right]^{\frac{1}{2}} \text{ m/s}$$

$$= \left[0.1985163646 8 \times 10^{14}\right]^{\frac{1}{2}} \text{ m/s}$$

$$= 0.4455 \times 10^{7} \text{ m/s}$$

Angle of propellation

1. As the reduced mass converts into energy, the total energy (E_T) propell both the particles with equal and opposite momentum according to a ray (line) perpendicular to the direction (line) of the velocity of the compound nucleus ($\vec{V}_{CN}$).

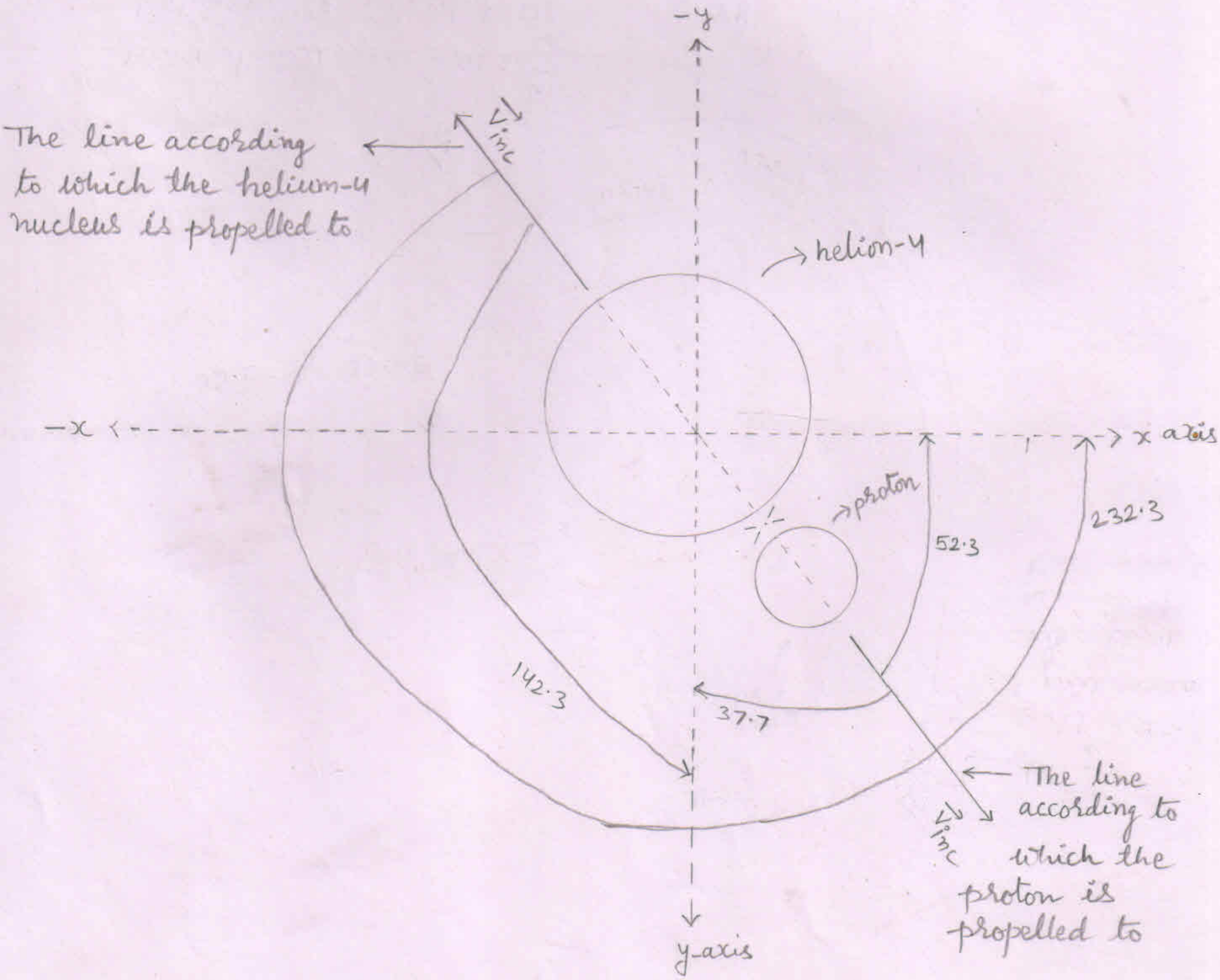
2. We know that when there a fusion process occures, then we find the lighter nucleus in the forward direction [or in the direction of ion beam or in the direction of the velocity of the compound nucleus ($\vec{V}_{CN}$).]

3. At point 'F' as $\vec{V}_{CN}$ makes 142.3 degree angle with x-axis, 52.3 degree angle with y-axis. and 90° angle with z-axis.

4. So, the proton is propelled making 52.3 degree angle with x-axis, 37.7 degree angle with y-axis and 90° angle with z-axis.

5. While the helium-4 nucleus is propelled making 232.3 degree angle with x-axis, 142.3 degree angle with y-axis and 90° angle with z-axis.

propellation of the particles



Components of the increased velocity ($\vec{v}_{inc}$) of the particles

I. For proton

1. $\vec{v}_x = v_{inc} \cos\alpha$

$v_{inc} = 1.7699 \times 10^7$ m/s

$\cos\alpha = \cos(52.3) = 0.61$

$\Rightarrow \vec{v}_x = 1.7699 \times 10^7 \times 0.61$ m/s

$= 1.0796 \times 10^7$ m/s

2. $\vec{v}_y = v_{inc} \cos\beta$

$\cos\beta = \cos(37.7) = 0.79$

$\Rightarrow \vec{v}_y = 1.7699 \times 10^7 \times 0.79$ m/s

$= 1.3982 \times 10^7$ m/s

3. $\vec{v}_z = v_{inc} \cos\gamma$

$\cos\gamma = \cos 90^\circ = 0$

$\Rightarrow \vec{v}_z = 1.7699 \times 10^7 \times 0$ m/s

$= 0$ m/s

II. For helion-4

1. $\vec{v}_x = v_{inc} \cos\alpha$

$v_{inc} = 0.4455 \times 10^7$ m/s

$\cos\alpha = \cos(232.3) = -\cos(52.3) = -0.61$

$\Rightarrow \vec{v}_x = 0.4455 \times 10^7 \times (-0.61)$ m/s

$= -0.2717 \times 10^7$ m/s

2. $\vec{v}_y = v_{inc} \cos\beta$

$\cos\beta = \cos(142.3) = -\cos(37.7) = -0.79$

$\Rightarrow \vec{v}_y = 0.4455 \times 10^7 \times (-0.79)$ m/s

$= -0.3519 \times 10^7$ m/s

3. $\vec{v}_z = v_{inc} \cos\gamma$

$\cos\gamma = \cos 90^\circ = 0$

$\Rightarrow \vec{v}_z = 0.4455 \times 10^7 \times 0$ m/s $= 0$ m/s

Components of the final velocity ($\vec{v}_f$) of the particles

I. For proton

According to	Inhereted velocity ($\vec{v}_{inh}$)	Increased velocity ($\vec{v}_{inc}$)	Final velocity ($\vec{v}_f$) $\vec{v}_f = \vec{v}_{inh} + \vec{v}_{inc}$
x-axis	$\vec{v}_x = -0.9137 \times 10^7$ m/s	$\vec{v}_x = 1.0796 \times 10^7$ m/s	$\vec{v}_x = 0.1659 \times 10^7$ m/s
y-axis	$\vec{v}_y = 0.7047 \times 10^7$ m/s	$\vec{v}_y = 1.3982 \times 10^7$ m/s	$\vec{v}_y = 2.1029 \times 10^7$ m/s
z-axis	$\vec{v}_z = 0$ m/s	$\vec{v}_z = 0$ m/s	$\vec{v}_z = 0$ m/s

II. For helion-4

According to	Inhereted velocity ($\vec{v}_{inh}$)	Increased velocity ($\vec{v}_{inc}$)	Final velocity ($\vec{v}_f$) $\vec{v}_f = \vec{v}_{inh} + \vec{v}_{inc}$
x-axis	$\vec{v}_x = -0.9137 \times 10^7$ m/s	$\vec{v}_x = -0.2717 \times 10^7$ m/s	$\vec{v}_x = -1.1854 \times 10^7$ m/s
y-axis	$\vec{v}_y = 0.7047 \times 10^7$ m/s	$\vec{v}_y = -0.3519 \times 10^7$ m/s	$\vec{v}_y = 0.3528 \times 10^7$ m/s
z-axis	$\vec{v}_z = 0$ m/s	$\vec{v}_z = 0$ m/s	$\vec{v}_z = 0$ m/s

Final velocity of the proton

$$v_f^2 = v_x^2 + v_y^2 + v_z^2$$

$v_x = 0.1659 \times 10^7$ m/s
$v_y = 2.1029 \times 10^7$ m/s
$v_z = 0$ m/s

$$\Rightarrow v_f^2 = (0.1659 \times 10^7)^2 + (2.1029 \times 10^7)^2 + (0)^2 \quad m^2/s^2$$

$$\Rightarrow v_f^2 = (0.02752281 \times 10^{14}) + (4.42218841 \times 10^{14}) + (0) \quad m^2/s^2$$

$$\Rightarrow v_f^2 = 4.44971122 \times 10^{14} \quad m^2/s^2$$

$$\Rightarrow v_f^2 = 2.1094 \times 10^7 \quad m/s$$

Final kinetic energy of the proton

$$E_p = \frac{1}{2} m_p v_f^2$$

$v_f^2 = 4.44971122 \times 10^{14}$ m^2/s^2

$$\Rightarrow E_p = \frac{1}{2} \times 1.6726 \times 10^{-27} \times 4.44971122 \times 10^{14} \quad J$$

$$\Rightarrow E_p = 3.72129349328 \times 10^{-13} \quad J$$

$$\Rightarrow E_p = 2.3258 \quad Mev$$

$$\Rightarrow m_p v_f^2 = 1.6726 \times 10^{-27} \times 4.44971122 \times 10^{14} \quad J$$
$$= 7.4425 \times 10^{-13} \quad J$$

Final velocity of the helion-4

$$v_f^2 = v_x^2 + v_y^2 + v_z^2$$

$v_x = 1.1854 \times 10^7$ m/s
$v_y = 0.3528 \times 10^7$ m/s
$v_z = 0$ m/s

$$\Rightarrow v_f^2 = (1.1854 \times 10^7)^2 + (0.3528 \times 10^7)^2 + (0)^2 \ m^2/s^2$$

$$\Rightarrow v_f^2 = (1.40517316 \times 10^{14}) + (0.12446784 \times 10^{14}) + (0) \ m^2/s^2$$

$$\Rightarrow v_f^2 = 1.529641 \times 10^{14} \ m^2/s^2$$

$$\Rightarrow v_f = 1.2367 \times 10^7 \ m/s$$

Final kinetic energy of the helion-4

$$E = \frac{1}{2} m_{He\text{-}4} v_f^2$$

$v_f^2 = 1.529641 \times 10^{14}$ m²/s²

$$\Rightarrow E = \frac{1}{2} \times 6.64449 \times 10^{-27} \times 1.529641 \times 10^{14} \ J$$

$$\Rightarrow E = 5.081842164 \times 10^{-13} \ J$$

$$\Rightarrow E = 3.1761 \ MeV$$

$$\Rightarrow m_{He\text{-}4} v_f^2 = 6.64449 \times 10^{-27} \times 1.529641 \times 10^{14} \ J$$
$$= 10.1636 \times 10^{-13} \ J$$

Acting forces on the proton

1. $F_y = q V_x B_z \sin\theta$

$\vec{V_x} = 0.1659 \times 10^7$ m/s

$\vec{B_z} = -1$ Tesla

$q = 1.6 \times 10^{-19}$ C

$\sin\theta = \sin 90^\circ = 1$

$\Rightarrow F_y = 1.6 \times 10^{-19} \times 0.1659 \times 10^7 \times 1 \times 1$ N

$= 0.2654 \times 10^{-12}$ N

From the right hand palm rule, the direction of force $\vec{F_y}$ is according to $-y$ axis. So,

$$\vec{F_y} = -0.2654 \times 10^{-12} \text{ N}$$

2. $F_z = q V_x B_y \sin\theta$

$\vec{B_y} = 1$ Tesla

$\sin\theta = \sin 90^\circ = 1$

$\Rightarrow F_z = 1.6 \times 10^{-19} \times 0.1659 \times 10^7 \times 1 \times 1$ N

$= 0.2654 \times 10^{-12}$ N

From the right hand palm rule, the direction of force $\vec{F_z}$ is according to $-z$ axis. So,

$$\vec{F_z} = -0.2654 \times 10^{-12} \text{ N}$$

3. $F_x = q V_y B_z \sin\theta$

$\vec{V_y} = 2.1029 \times 10^7$ m/s

$\vec{B_z} = -1$ Tesla

$\sin\theta = \sin 90^\circ = 1$

$\Rightarrow F_x = 1.6 \times 10^{-19} \times 2.1029 \times 10^7 \times 1 \times 1$ N

$= 3.3646 \times 10^{-12}$ N

From the right hand palm rule, the direction of force $\vec{F_x}$ is according to $+x$ axis. So,

4. Resultant force (F_R):

$$F_R^2 = F_x^2 + F_y^2 + F_z^2$$

$$F_x = 3.3646 \times 10^{-12} \ N$$

$$F = F_y = F_z = 0.2654 \times 10^{-12} \ N$$

$$\Rightarrow F_R^2 = F_x^2 + 2F^2$$

$$\Rightarrow F_R^2 = (3.3646 \times 10^{-12})^2 + 2(0.2654 \times 10^{-12})^2 \ N^2$$

$$\Rightarrow F_R^2 = (11.32053316 \times 10^{-24}) + 2(0.07043716 \times 10^{-24}) \ N^2$$

$$\Rightarrow F_R^2 = (11.32053316 \times 10^{-24}) + (0.14087432 \times 10^{-24}) \ N^2$$

$$\Rightarrow F_R^2 = 11.46140748 \times 10^{-24} \ N^2$$

$$\Rightarrow F_R = 3.3854 \times 10^{-12} \ N$$

5. Radius of the circular orbit followed by the proton

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

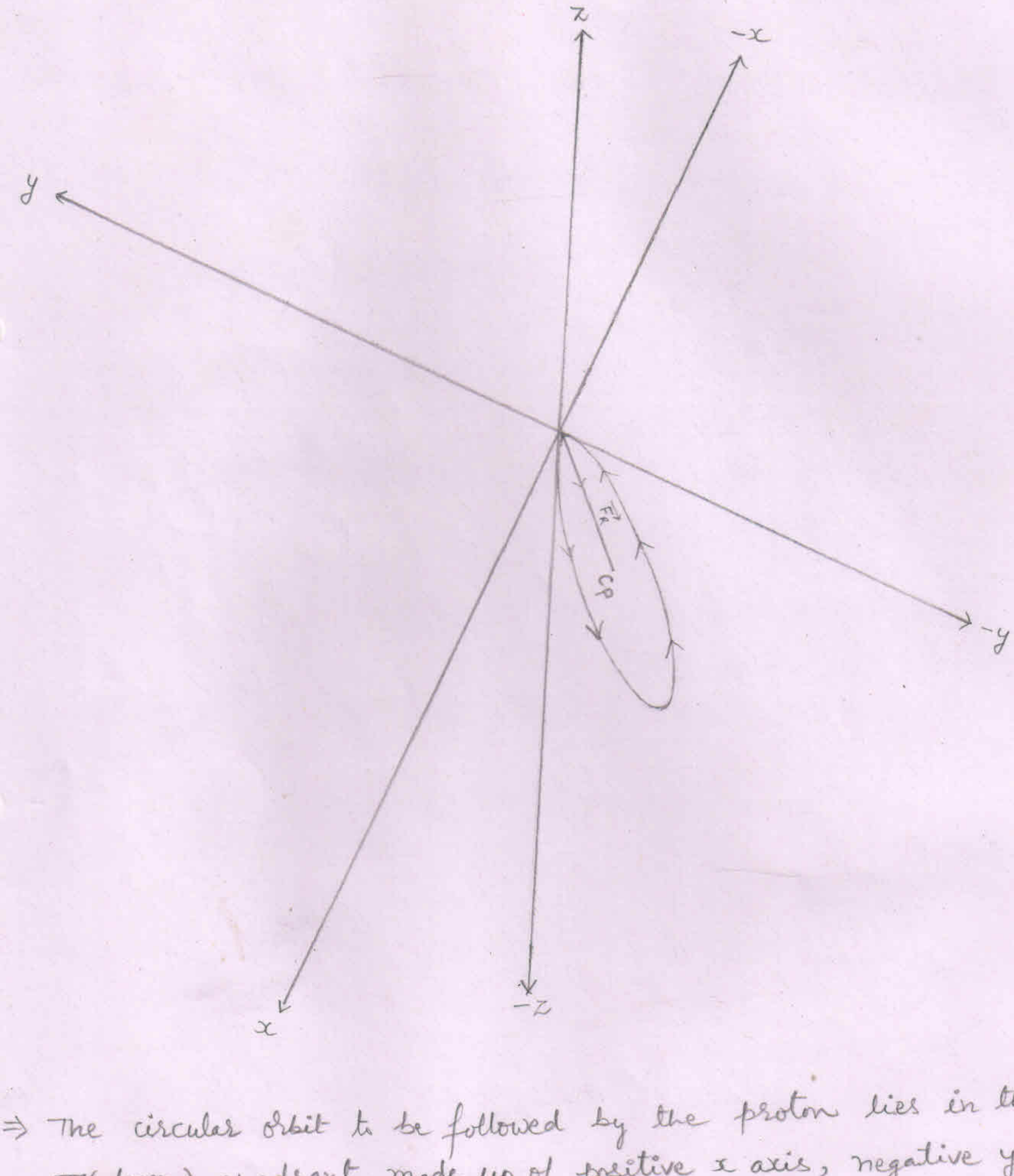
$mv^2 = 7.4425 \times 10^{-13}$ J

$F_R = 3.3854 \times 10^{-12}$ N

$$\Rightarrow r = \frac{7.4425 \times 10^{-13}}{3.3854 \times 10^{-12}} \text{ m}$$

$$\Rightarrow r = 2.19841 \times 10^{-1} \text{ m}$$

$$\Rightarrow r = 21.9841 \times 10^{-2} \text{ m}$$



$\Rightarrow$ The circular orbit to be followed by the proton lies in the IV (down) quadrant made up of positive x axis, negative y axis and the negative z axis

$\Rightarrow$ C_p = center of the circle to be followed by the proton

Angles that make the resultant force ($\vec{F_R}$) [acting on the proton when the proton is at point 'F'] with positive x, y and z-axes.

1. With x-axis

$$\cos\alpha = \frac{F_R \cos\alpha}{F_R} = \frac{\vec{F_x}}{F_R} = \frac{3.3646 \times 10^{-12}}{3.3854 \times 10^{-12}} \frac{N}{N}$$

$\Rightarrow \cos\alpha = 0.9938$

$\Rightarrow \alpha \simeq 6.5$ degree $[\because \cos(6.5) = 0.9935]$

2. With y-axis

$$\cos\beta = \frac{F_R \cos\beta}{F_R} = \frac{\vec{F_y}}{F_R} = \frac{-0.2654 \times 10^{-12}}{3.3854 \times 10^{-12}} \frac{N}{N}$$

$\Rightarrow \cos\beta = -0.0783$

$\Rightarrow \beta \simeq 94.4$ degree $[\because \cos(94.4) = -0.0767]$

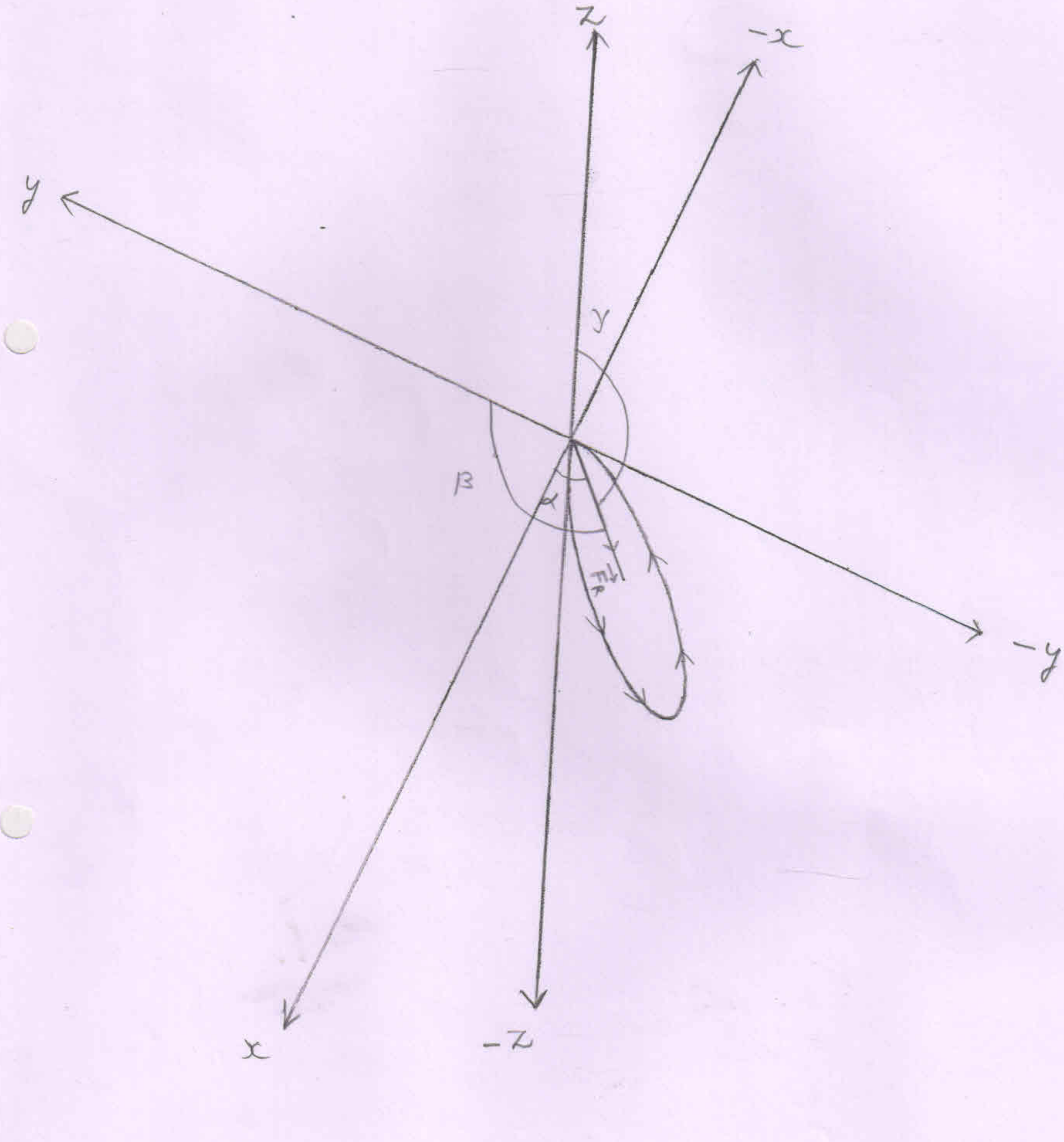
3. With z-axis

$$\cos\gamma = \frac{F_R \cos\gamma}{F_R} = \frac{\vec{F_z}}{F_R} = \frac{-0.2654 \times 10^{-12}}{3.3854 \times 10^{-12}} \frac{N}{N}$$

$\Rightarrow \cos\gamma = -0.0783$

$\Rightarrow \gamma \simeq 94.4$ degree

Angles that make the resultant force ($\vec{F_R}$) at point F with positive x, y and z axes.



where,

$\alpha \simeq 6.5$

$\beta \simeq 94.4$

$\gamma \simeq 94.4$

The cartesian coordinates of the points $P_1(x_1, y_1, z_1)$ and $P_2(x_2, y_2, z_2)$ located on the circumfrence of the circle obtained by the proton

1. $\cos\alpha = \dfrac{x_2 - x_1}{d}$

$$d = 2 \times r$$
$$= 2 \times 21.9841 \times 10^{-2}\,m$$
$$= 43.9682 \times 10^{-2}\,m$$

$$\cos\alpha = 0.99$$

$\Rightarrow x_2 - x_1 = d \times \cos\alpha$

$\Rightarrow x_2 - x_1 = 43.9682 \times 10^{-2} \times 0.99\,m$

$\Rightarrow x_2 - x_1 = 43.5285 \times 10^{-2}\,m$

$\Rightarrow x_2 = 43.5285 \times 10^{-2}\,m \quad [\because x_1 = 0]$

2. $\cos\beta = \dfrac{y_2 - y_1}{d}$

$$\cos\beta = -0.07$$

$\Rightarrow y_2 - y_1 = d \times \cos\beta$

$\Rightarrow y_2 - y_1 = 43.9682 \times 10^{-2} \times (-0.07)\,m$

$\Rightarrow y_2 - y_1 = -3.0777 \times 10^{-2}\,m$

$\Rightarrow y_2 = -3.0777 \times 10^{-2}\,m \quad [\because y_1 = 0]$

3. $\cos\gamma = \dfrac{z_2 - z_1}{d}$

$$\cos\gamma = -0.07$$

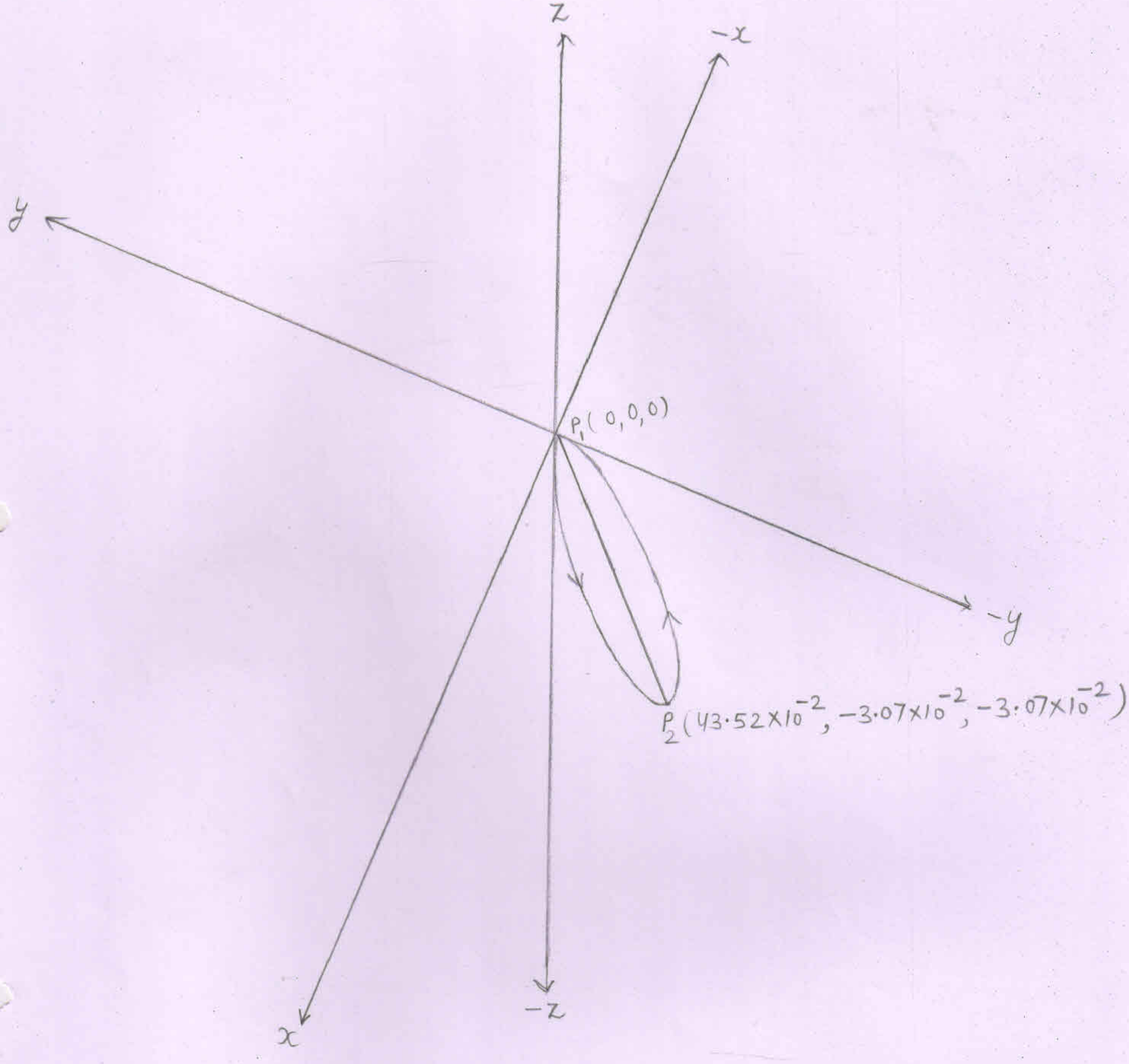
$\Rightarrow z_2 - z_1 = d \times \cos\gamma$

$\Rightarrow z_2 - z_1 = 43.9682 \times 10^{-2} \times (-0.07)\,m$

$\Rightarrow z_2 - z_1 = -3.0777 \times 10^{-2}\,m$

$\Rightarrow z_2 = -3.0777 \times 10^{-2}\,m \quad [\because z_1 = 0]$

The cartesian coordinates of the points $P_1(x_1, y_1, z_1)$ and $P_2(x_2, y_2, z_2)$



⇒ The cartesian coordinates of the points $P_1(x_1, y_1, z_1)$ and $P_2(x_2, y_2, z_2)$ located on the circumfrence of the circle obtained by the proton.

⇒ The line $\overline{P_1 P_2}$ is the diameter of the circle.

Acting forces on the helion-4

1. $F_y = q V_x B_z \sin\theta$

$\vec{V}_x = -1.1854 \times 10^7$ m/s

$\vec{B}_z = -1$ Tesla

$q = 2 \times 1.6 \times 10^{-19}$ C

$\sin\theta = \sin 90^\circ = 1$

$\Rightarrow F_y = 2 \times 1.6 \times 10^{-19} \times 1.1854 \times 10^7 \times 1 \times 1$ N

$= 3.7932 \times 10^{-12}$ N

From the right hand palm rule, the direction of force $\vec{F}_y$ is according to $+y$ axis. So,

$$\vec{F}_y = 3.7932 \times 10^{-12} \text{ N}$$

2. $F_z = q V_x B_y \sin\theta$

$\vec{B}_y = 1$ Tesla

$\sin\theta = \sin 90^\circ = 1$

$\Rightarrow F_z = 2 \times 1.6 \times 10^{-19} \times 1.1854 \times 10^7 \times 1 \times 1$ N

$= 3.7932 \times 10^{-12}$ N

From the right hand palm rule, the direction of force $\vec{F}_z$ is according to $+z$ axis. So,

$$\vec{F}_z = 3.7932 \times 10^{-12} \text{ N}$$

3. $F_x = q V_y B_z \sin\theta$

$\vec{V}_y = 0.3528 \times 10^7$ m/s

$\vec{B}_z = -1$ Tesla

$\sin\theta = \sin 90^\circ = 1$

$\Rightarrow F_x = 2 \times 1.6 \times 10^{-19} \times 0.3528 \times 10^7 \times 1 \times 1$ N

$= 1.1289 \times 10^{-12}$ N

From the right hand palm rule, the direction of force $\vec{F}_x$ is according to $+x$ axis. So,

4. Resultant force (F_R):

$$F_R^2 = F_x^2 + F_y^2 + F_z^2$$

$$F_x = 1.1289 \times 10^{-12} \text{ N}$$

$$F = F_y = F_z = 3.7932 \times 10^{-12} \text{ N}$$

$$\Rightarrow F_R^2 = F_x^2 + 2F^2$$

$$\Rightarrow F_R^2 = (1.1289 \times 10^{-12})^2 + 2(3.7932 \times 10^{-12})^2 \text{ N}^2$$

$$\Rightarrow F_R^2 = (1.27441521 \times 10^{-24}) + 2(14.38836624 \times 10^{-24}) \text{ N}^2$$

$$\Rightarrow F_R^2 = (1.27441521 \times 10^{-24}) + (28.77673248 \times 10^{-24}) \text{ N}^2$$

$$\Rightarrow F_R^2 = 30.05114769 \times 10^{-24} \text{ N}^2$$

$$\Rightarrow F_R = 5.4818 \times 10^{-12} \text{ N}$$

Radius of the circular orbit followed by the helion-4 :-

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

$mv^2 = 10.1636 \times 10^{-13}$ J

$F_R = 5.4818 \times 10^{-12}$ N

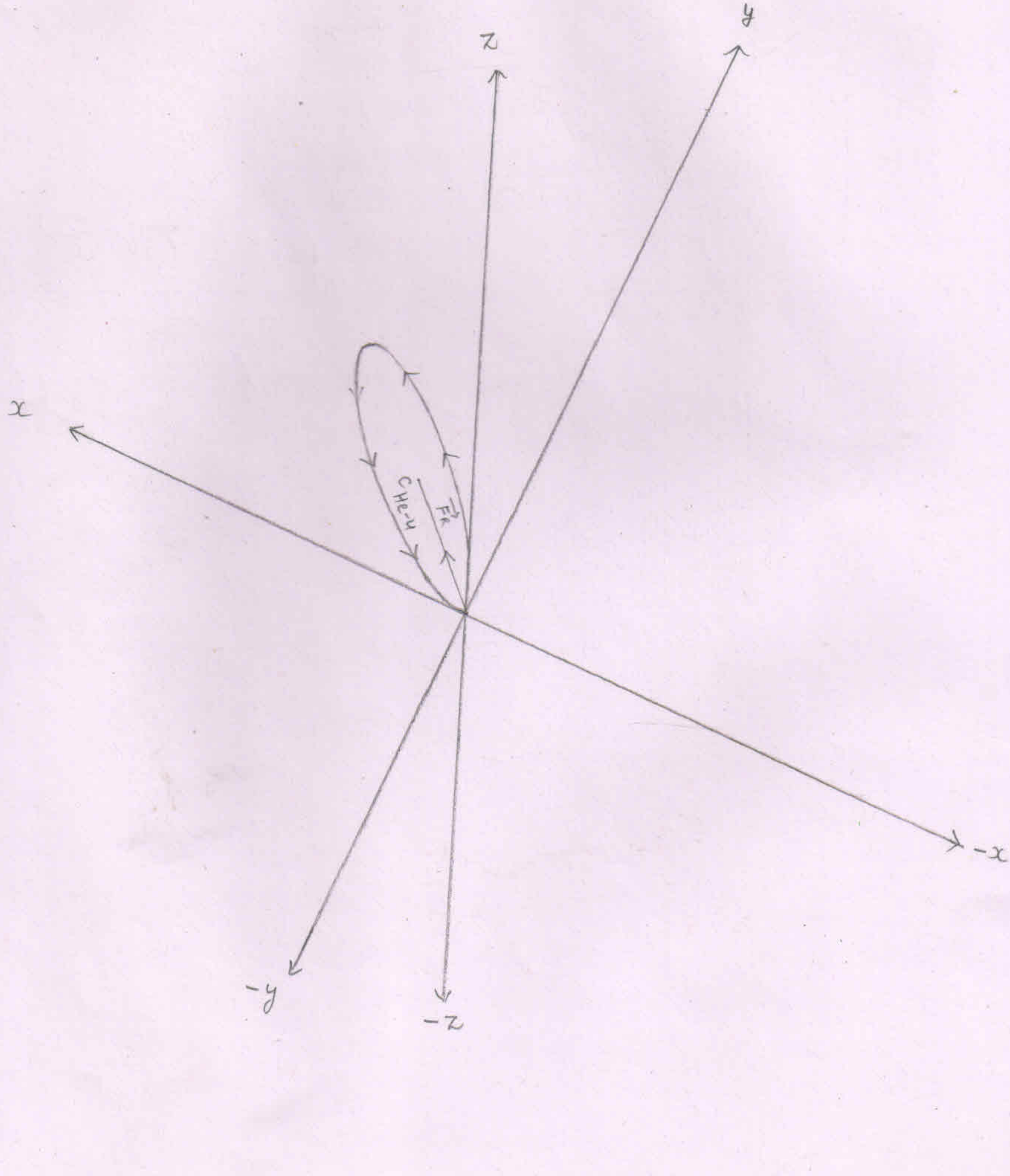
$$\Rightarrow r = \frac{10.1636 \times 10^{-13}}{5.4818 \times 10^{-12}} \text{ m}$$

$$\Rightarrow r = 1.85406 \times 10^{-1} \text{ m}$$

$$\Rightarrow r = 18.5406 \times 10^{-2} \text{ m}$$

$\Rightarrow$ The circular orbit to be followed by the helion-4 lies in the I (up) quadrant made up of positive x axis, positive y axis and the positive z axis.

$\Rightarrow C_{He-4}$ = centre of the circle to be followed by the helion-4



Angles that make the resultant force ($\vec{F_R}$) [acting on the helium-4 nucleus when the helium-4 is at point 'F'] with positive x, y and z-axes. :-

1. With x-axis

$$\cos\alpha = \frac{F_R \cos\alpha}{F_R} = \frac{\vec{F_x}}{F_R} = \frac{1.1289 \times 10^{-12}}{5.4818 \times 10^{-12}} \frac{N}{N}$$

$\Rightarrow \cos\alpha = 0.2059$

$\Rightarrow \alpha \simeq 78.2$ degree [$\because \cos(78.2) = 0.2044$]

2. With y-axis

$$\cos\beta = \frac{F_R \cos\beta}{F_R} = \frac{\vec{F_y}}{F_R} = \frac{3.7932 \times 10^{-12}}{5.4818 \times 10^{-12}} \frac{N}{N}$$

$\Rightarrow \cos\beta = 0.6919$

$\Rightarrow \beta \simeq 46.3$ degree [$\because \cos(46.3) = 0.6908$]

3. With z-axis

$$\cos\gamma = \frac{F_R \cos\gamma}{F_R} = \frac{\vec{F_z}}{F_R} = \frac{3.7932 \times 10^{-12}}{5.4818 \times 10^{-12}} \frac{N}{N}$$

$\Rightarrow \cos\gamma = 0.6919$

$\Rightarrow \gamma \simeq 46.3$ degree

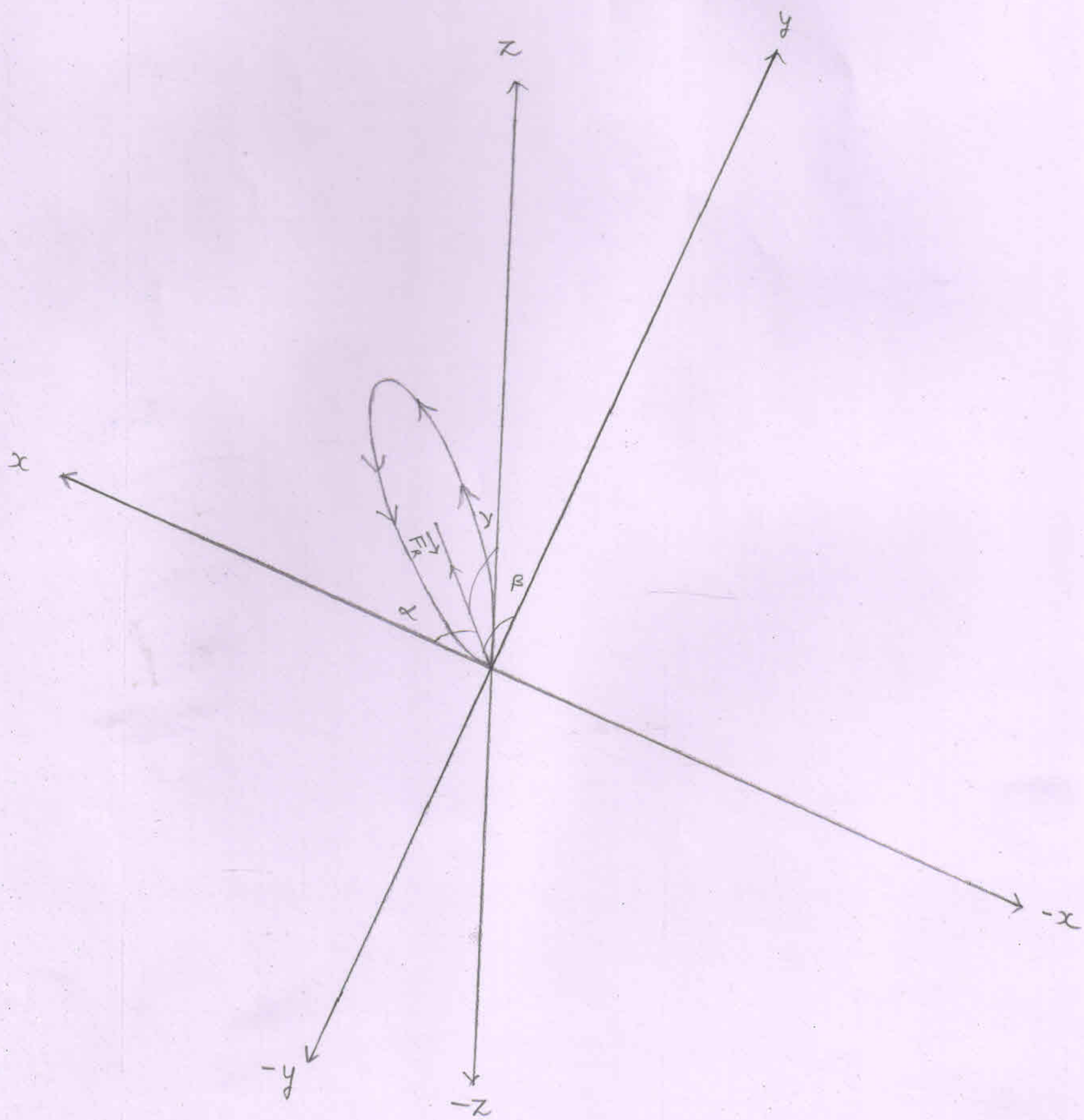
Angles that make the resultant force ($\vec{F_R}$) at point F with positive x, y and z axes.

⇒ Where,

$\alpha \simeq 78.2$

$\beta \simeq 46.3$

$\gamma \simeq 46.3$



The cartesian coordinates of the points $P_1(x_1, y_1, z_1)$ and $P_2(x_2, y_2, z_2)$ located on the circumfrence of the circle obtained by the helion-4.

1. $\cos\alpha = \dfrac{x_2 - x_1}{d}$

$$d = 2 \times r$$
$$= 2 \times 18.5406 \times 10^{-2}\ m$$
$$= 37.0812 \times 10^{-2}\ m$$
$$\cos\alpha = 0.20$$

$\Rightarrow x_2 - x_1 = d \times \cos\alpha$

$\Rightarrow x_2 - x_1 = 37.0812 \times 10^{-2} \times 0.20\ m$

$\Rightarrow x_2 - x_1 = 7.4162 \times 10^{-2}\ m$

$\Rightarrow x_2 = 7.4162 \times 10^{-2}\ m \quad [\because x_1 = 0]$

2. $\cos\beta = \dfrac{y_2 - y_1}{d}$

$$\cos\beta = 0.69$$

$\Rightarrow y_2 - y_1 = d \times \cos\beta$

$\Rightarrow y_2 - y_1 = 37.0812 \times 10^{-2} \times 0.69\ m$

$\Rightarrow y_2 - y_1 = 25.5860 \times 10^{-2}\ m$

$\Rightarrow y_2 = 25.5860 \times 10^{-2}\ m \quad [\because y_1 = 0]$

3. $\cos\gamma = \dfrac{z_2 - z_1}{d}$

$$\cos\gamma = 0.69$$

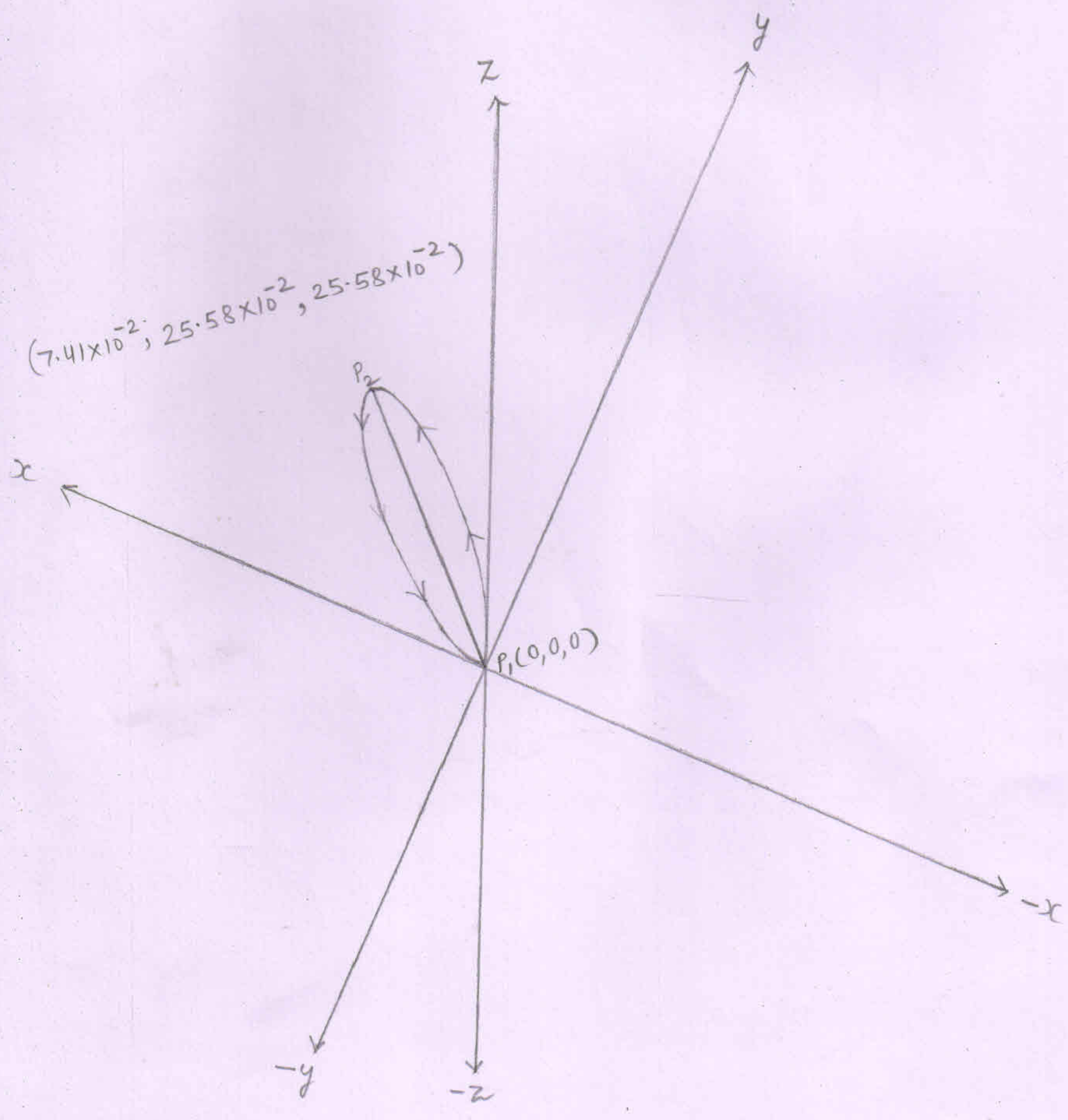
$\Rightarrow z_2 - z_1 = d \times \cos\gamma$

$\Rightarrow z_2 - z_1 = 37.0812 \times 10^{-2} \times 0.69\ m$

$\Rightarrow z_2 - z_1 = 25.5860 \times 10^{-2}\ m$

$\Rightarrow z_2 = 25.5860 \times 10^{-2}\ m \quad [\because z_1 = 0]$

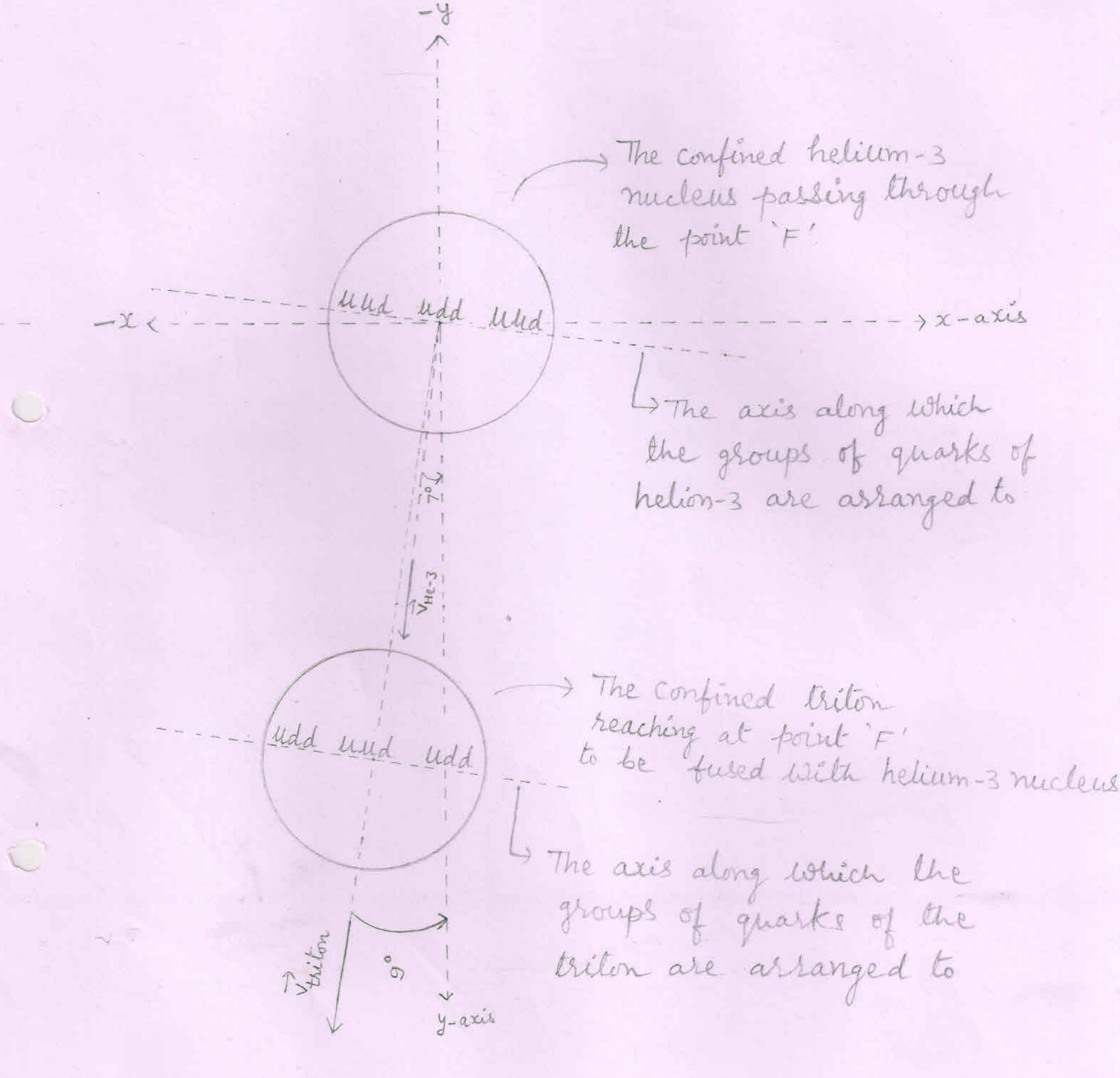
The cartesian coordinates of the points $P_1(x_1, y_1, z_1)$ and $P_2(x_2, y_2, z_2)$



For fusion reaction 6(ii) : $^{3}_{1}H + ^{3}_{2}He \longrightarrow ^{4}_{2}He + ^{2}_{1}H$

1. Interaction of nuclei :-

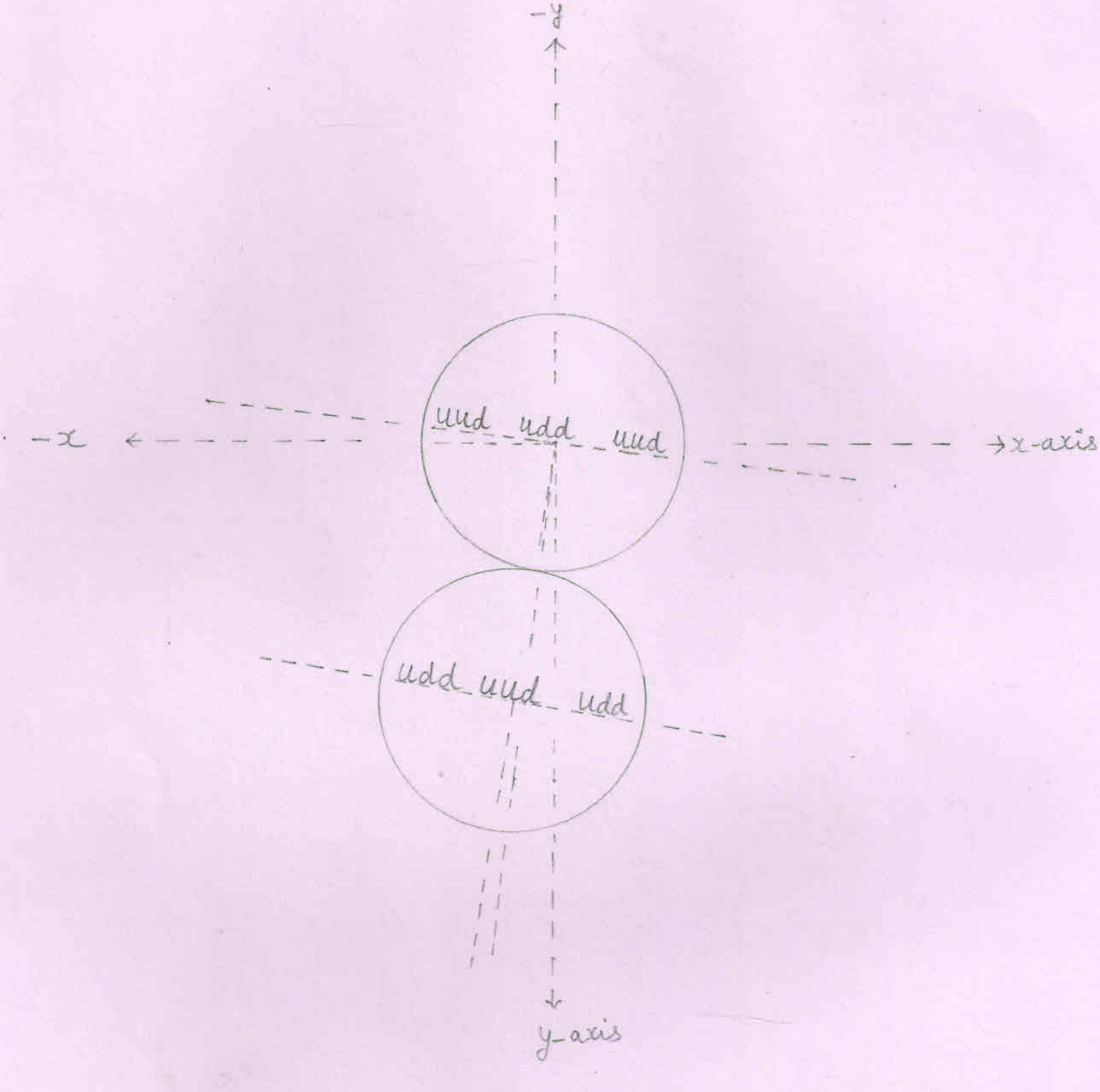
The confined triton reaches at point 'F' and interacts [experiences a repulsive force due to confined helium-3 nucleus passing through the point 'F'] with the confined helium-3 nucleus at point 'F'. The confined triton overcomes the electrostatic repulsive force and – a like two solid spheres join – the confined triton dissimilarly joins with the confined helium-3 nucleus.



□ 1 (1)

Interaction of nuclei

Interaction of nuclei

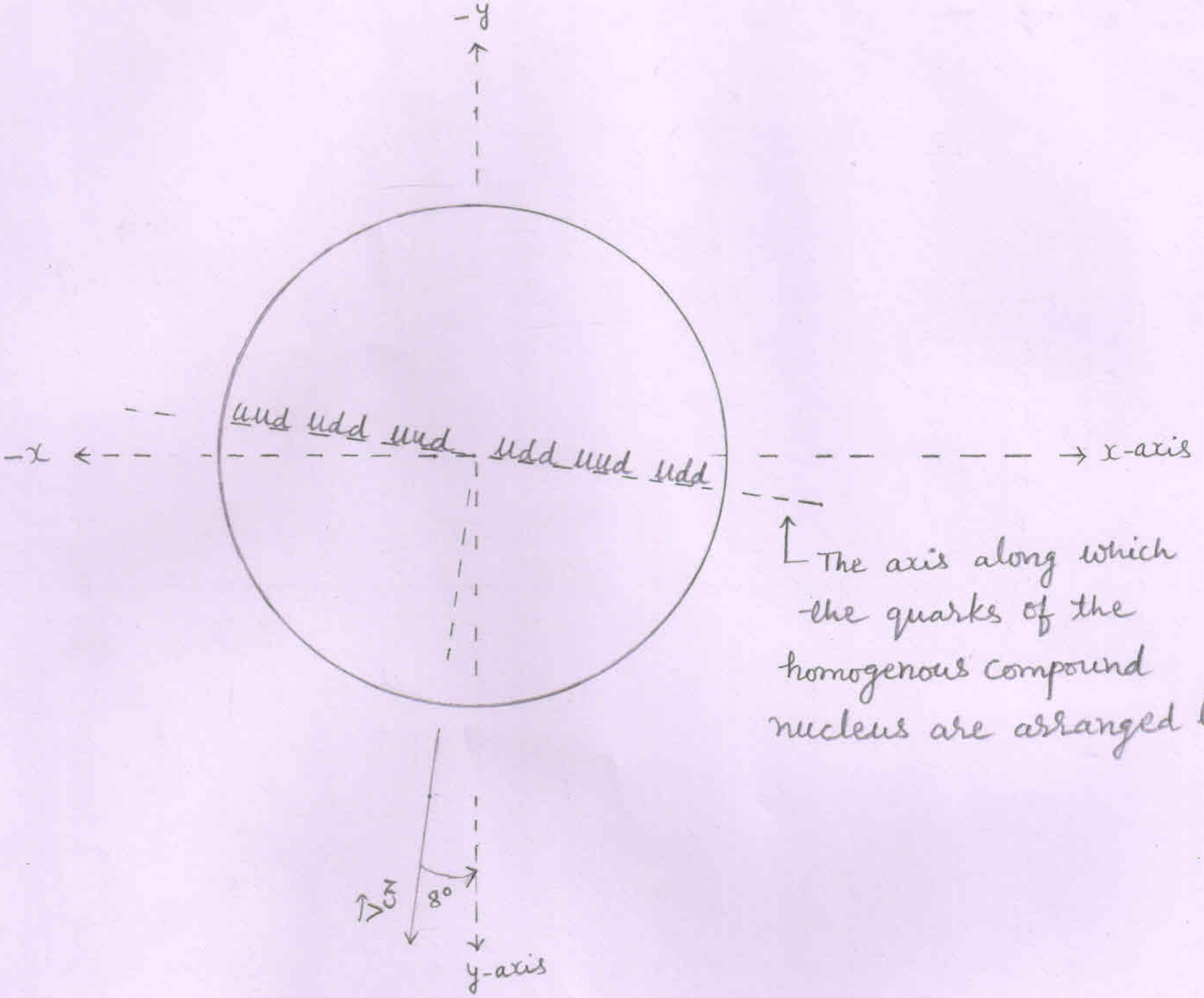


1 (2)

The dissimilarly joined nuclei

2. Formation of the homogenous compound nucleus :-
The constituents (quarks and gluons) of the dissimilarly joined nuclei (the triton and the helion-3) behave like a liquid and form the homogenous compound nucleus having similarly distributed groups of quarks with similarly distributed surrounding gluons.

Thus within the homogenous compound nucleus - each group of quarks is surrounded by gluons in equal proportion. So, within the homogenous compound nucleus there are 6 groups of quarks surrounded by the gluons.



□

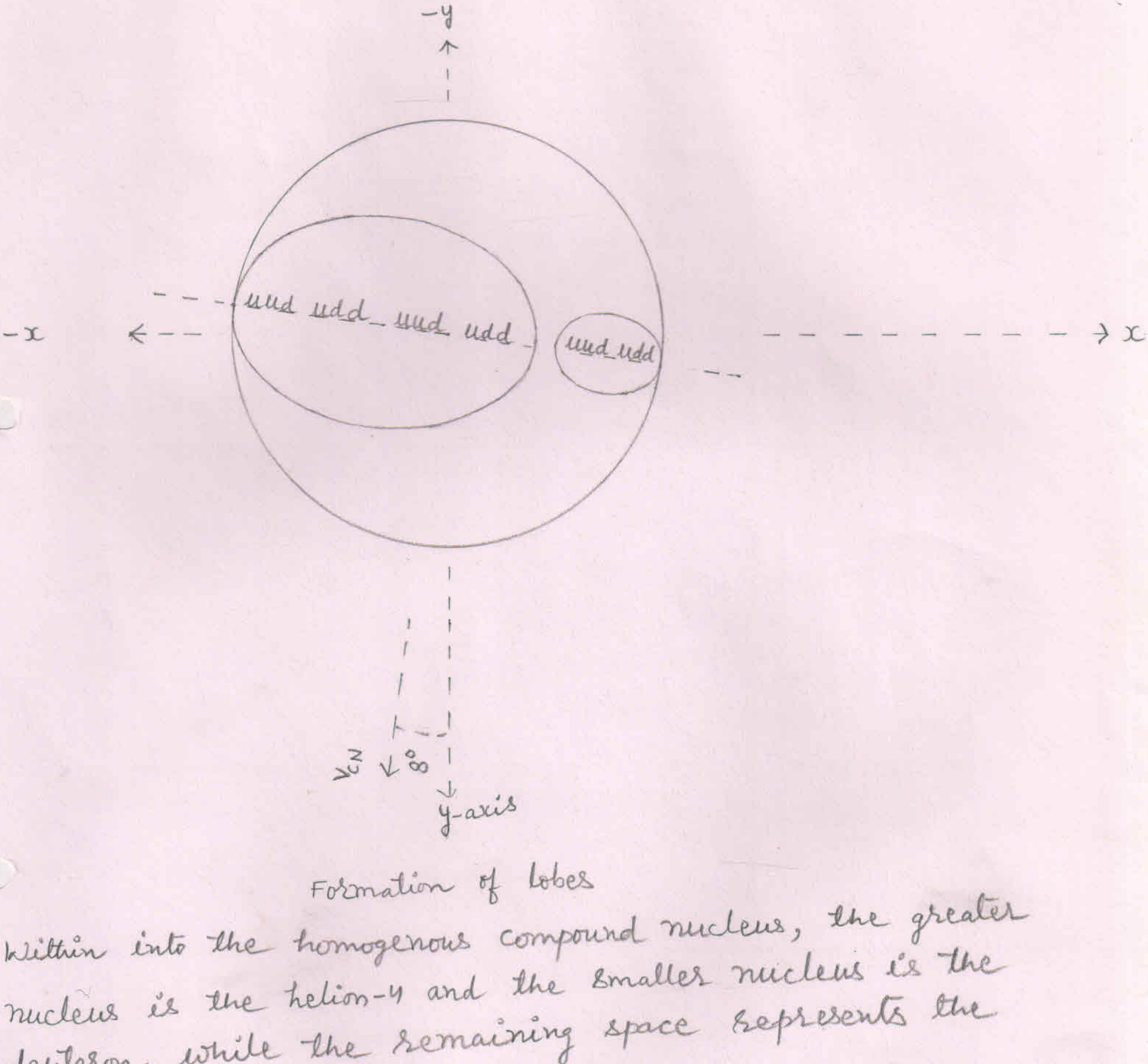
The homogenous compound nucleus.

3. Formation of lobes within into the homogenous compound nucleus or the transformation of the homogenous compound nucleus into the heterogenous compound nucleus :-

The central group of quarks with its surrounding gluons to become a stable and the next higher nucleus (the helion-4) than the reactant one (the helion-3) includes the other three (nearby located) groups of quarks with their surrounding gluons and rearrange to form the 'A' lobe of the heterogenous compound nucleus.

While the remaining groups of quarks to become a stable nucleus (the deuteron) includes the other one (nearby located) group of quarks with its surrounding gluons [out of the available group of quarks with its surrounding gluons that is not involved in the formation of the lobe 'A'] and rearrange to form the 'B' lobe of the heterogenous compound nucleus.

Thus, due to formation of two dissimilar lobes within into the homogenous compound nucleus, the homogenous compound nucleus transforms into the heterogenous compound nucleus.



Formation of lobes

⇒ Within into the homogenous compound nucleus, the greater nucleus is the helion-4 and the smaller nucleus is the deuteron while the remaining space represents the remaining gluons.

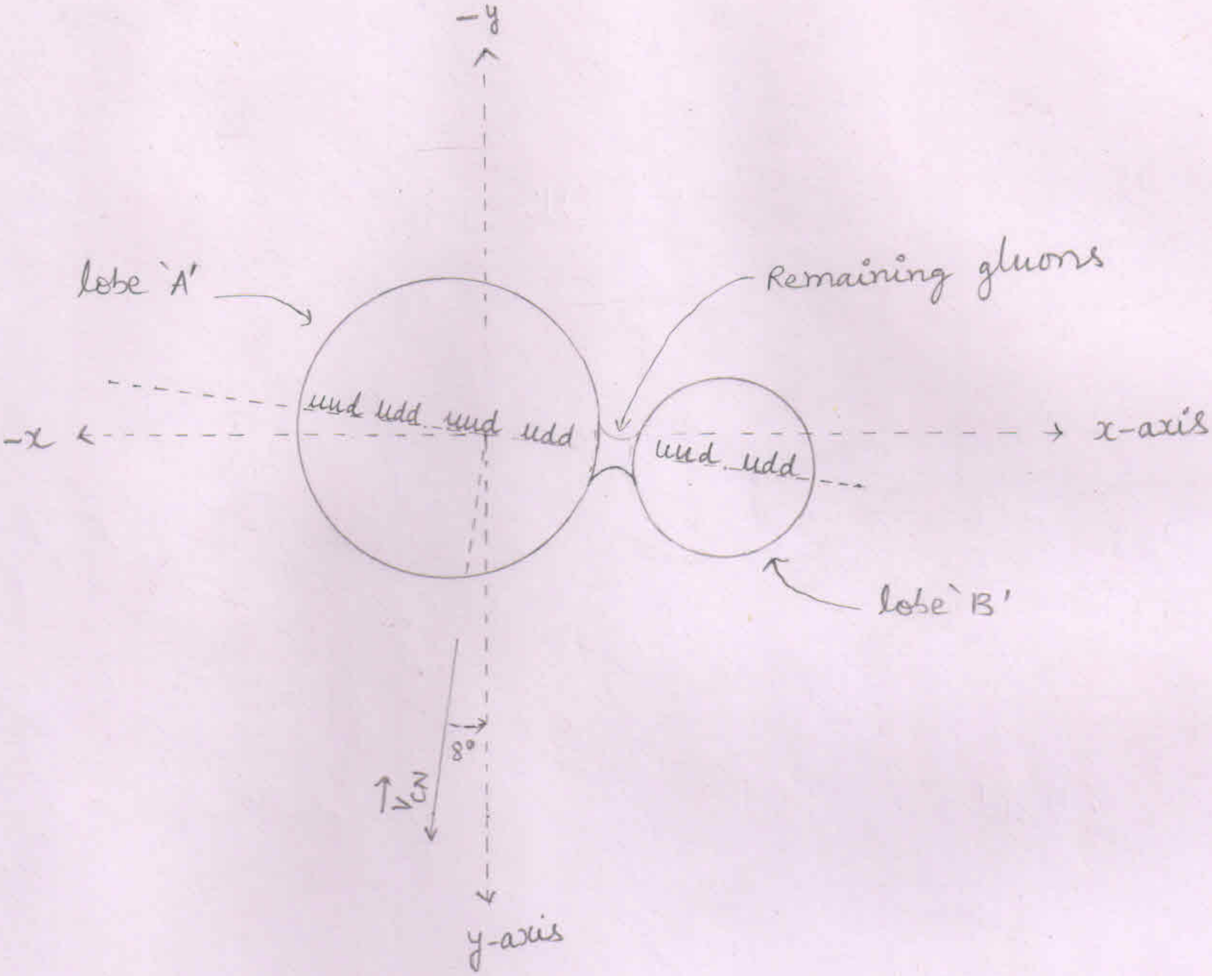
⇒ Within into the homogenous compound nucleus, the greater nucleus is the lobe 'A' while the smaller nucleus is the lobe 'B'.

4. Final stage of the heterogenous compound nucleus :-

The process of formation of lobes creates voids between the lobes. So, the remaining gluons [or the mass that is not involved in the formation of any lobe] rearrange to fill the void(s) between the lobes and thus the remaining gluons form a node between the two dissimilar lobes of the heterogenous compound nucleus.

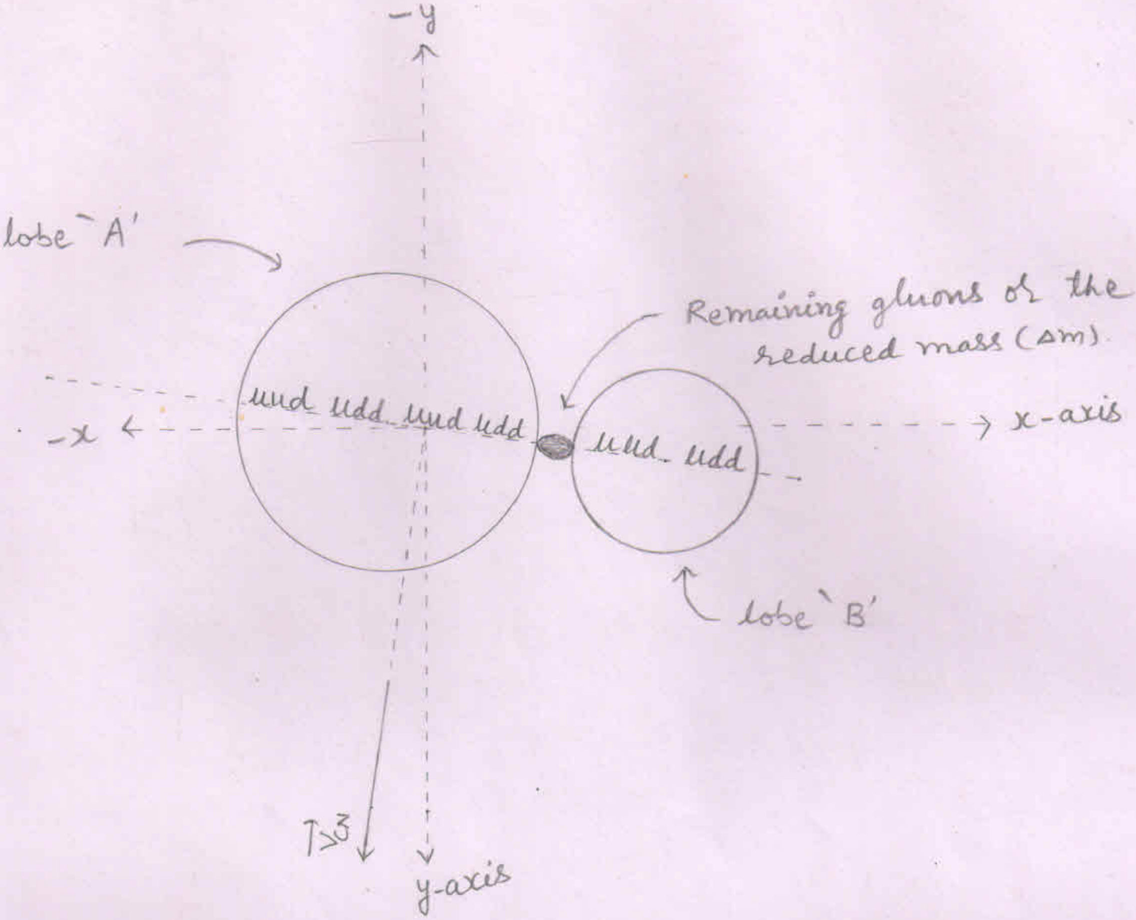
Thus, the reduced mass (or the remaining gluons) keeps both the dissimilar lobes - of the heterogenous compound nucleus - joined them together.

So, finally, the heterogenous compound nucleus becomes like an abnormal digit eight or becomes like a dumbbell.



$\boxed{4(1)}$

The heterogenous compound nucleus



4(2)

Final Stage of the heterogenous compound nucleus

The splitting of the heterogenous compound nucleus:-

⇒ The heterogenous compound nucleus, due to its instability, splits according to the lines parallel to the direction of the velocity of the compound nucleus ($\vec{V}_{CN}$) into three particles - the helium-4 nucleus, the deuteron and the reduced mass (Δm).

Out of them, the two particles (the helion-4 and the deuteron) are stable while the third one (reduced mass) is unstable.

⇒ According to the law of inertia, each particle that has separated from the compound nucleus, has an inherited velocity ($\vec{V}_{inh}$) equal to the velocity of the compound nucleus ($\vec{V}_{CN}$).

⇒ So, for conservation of momentum

$$M\vec{V}_{CN} = (m_{he-4} + \Delta m + m_d)\,\vec{V}_{CN}$$

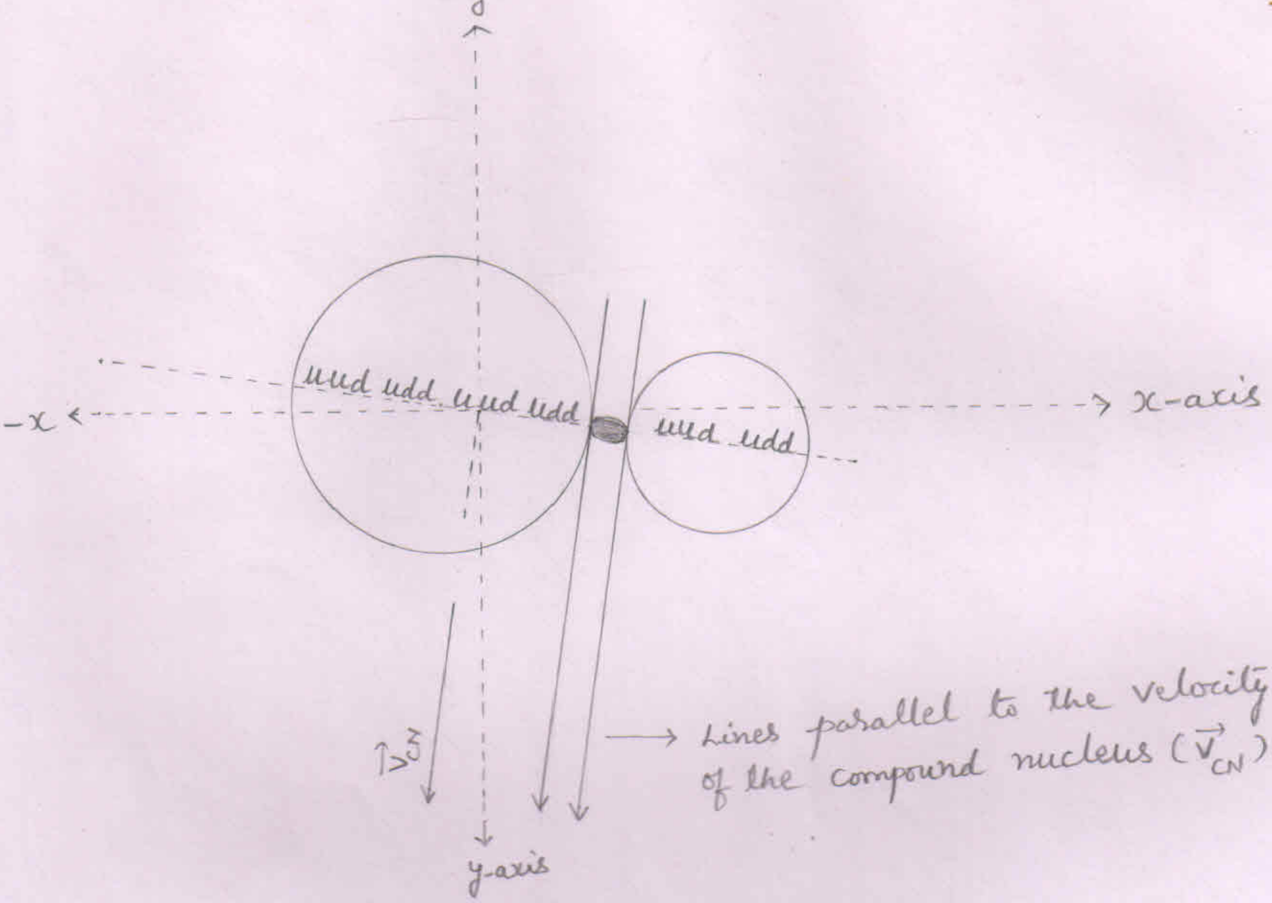
Where,

M = mass of the compound nucleus
$\vec{V}_{CN}$ = velocity of the compound nucleus

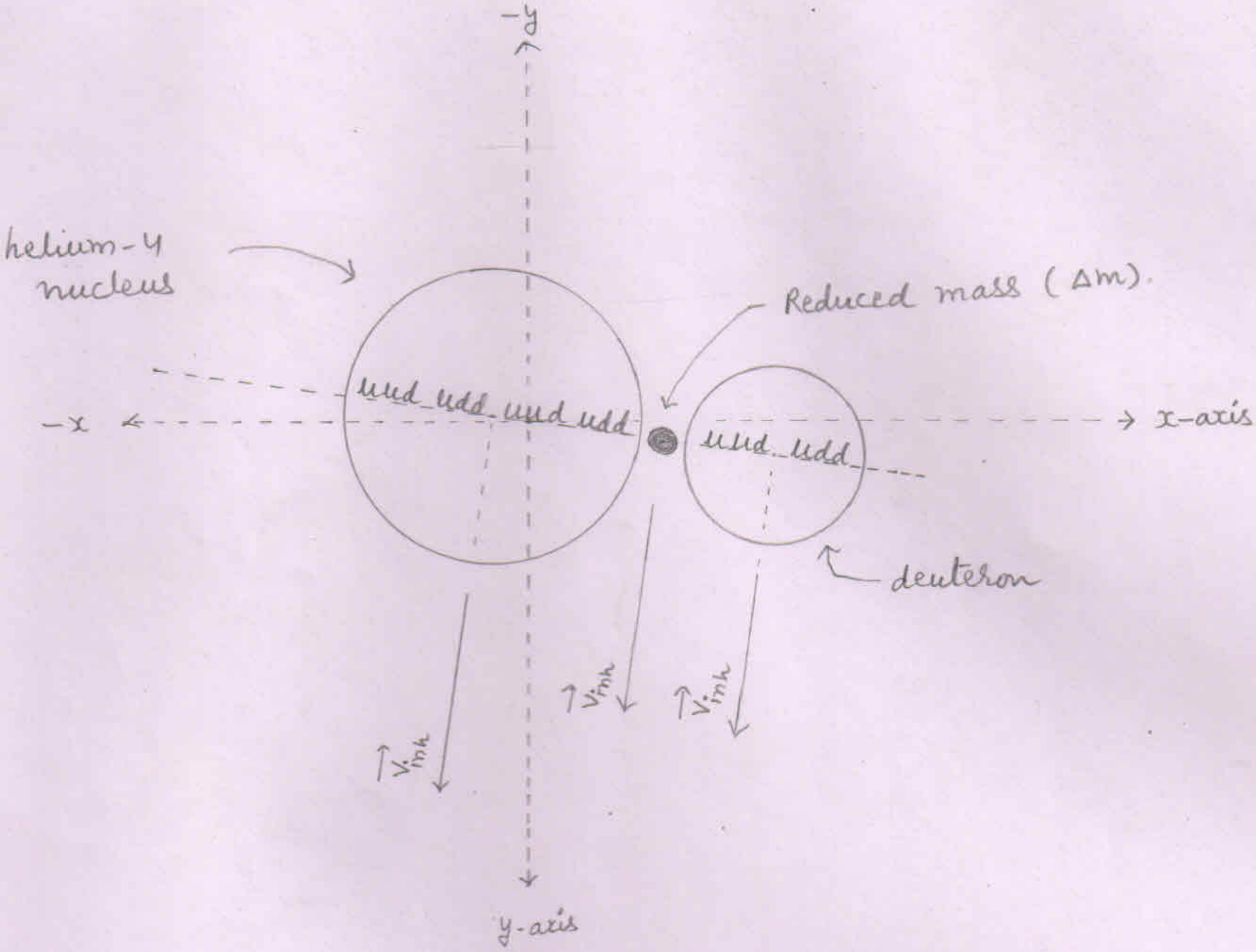
m_{he-4} = mass of the helium-4 nucleus

Δm = reduced mass
m_d = mass of the deuteron

The splitting of the heterogenous compound nucleus



The splitting of the heterogenous compound nucleus



⇒ Due to splitting of heterogenous compound nucleus, the three particles are produced - helium-4 nucleus, reduced mass (Δm) and the deuteron

Inhereted velocity of the particles

⇒ Each particle that has separated from the compound nucleus has an inhereted velocity ($\vec{V}_{inh}$) equal to the velocity of the compound nucleus ($\vec{V}_{CN}$).

I. Inhereted velocity (V_{inh}) of the helion-4

$$V_{inh} = V_{CN} = 0.8176 \times 10^{7}\ m/s$$

⇒ Components of the inhereted velocity ($\vec{V}_{inh}$) of the helium-4 nucleus :-

1. $\vec{V}_x = V_{inh} \cos\alpha = V_{CN} \cos\alpha = -0.1130 \times 10^{7}\ m/s$

2. $\vec{V}_y = V_{inh} \cos\beta = V_{CN} \cos\beta = 0.8098 \times 10^{7}\ m/s$

3. $\vec{V}_z = V_{inh} \cos\gamma = V_{CN} \cos\gamma = 0\ m/s$

II. Inhereted velocity (V_{inh}) of the deuteron

$$V_{inh} = V_{CN} = 0.8176 \times 10^{7}\ m/s$$

⇒ Components of the inhereted velocity ($\vec{V}_{inh}$) of the deuteron :-

1. $\vec{V}_x = V_{inh} \cos\alpha = V_{CN} \cos\alpha = -0.1130 \times 10^{7}\ m/s$

2. $\vec{V}_y = V_{inh} \cos\beta = V_{CN} \cos\beta = 0.8098 \times 10^{7}\ m/s$

3. $\vec{V}_z = V_{inh} \cos\gamma = V_{CN} \cos\gamma = 0\ m/s$

III. Inhereted velocity (V) of the reduced mass (Δm) :-

Propellation of the particles

1. Reduced mass (Δm) :

$$\Delta m = [m_t + m_{He-3}] - [m_{He-4} + m_d]$$

$$= [3.0155 + 3.0149] - [4.0015 + 2.0135] \text{ amu}$$

$$= [6.0304] - [6.015] \text{ amu}$$

$$\Delta m = 0.0154 \text{ amu}$$

$$= 0.0154 \times 1.6605 \times 10^{-27} \text{ kg}$$

$$\Delta m = 0.0255717 \times 10^{-27} \text{ kg}$$

2. Inhereted kinetic energy of the reduced mass

$$E_{inh} = \frac{1}{2} \Delta m V_{inh}^2 = \frac{1}{2} \Delta m V_{CN}^2$$

$$= \frac{1}{2} \times 0.0255717 \times 10^{-27} \times 0.66854504 \times 10^{14} \text{ J}$$

$$= 0.0085479 1659 \times 10^{-13} \text{ J}$$

$$= 0.0053 \text{ MeV}$$

3. Released energy (E_R) :

$$E_R = \Delta m c^2$$
$$= 0.0154 \times 931 \quad Mev$$
$$= 14.3374 \quad Mev$$

4. Total energy (E_T) :

$$E_T = E_{inh}^{\circ} + E_R$$

$$= [0.0053] + [14.3374] \quad Mev$$

$$= 14.3427 \quad Mev$$

Increased kinetic energy of the deuteron

$$E_{inc} = \frac{m_{He-4}}{m_{He-4} + m_d} \times E_T$$

$$= \frac{4.0015}{4.0015 + 2.0135} \times 14.3427 \quad \text{Mev}$$

$$= \frac{4.0015}{6.015} \times 14.3427 \quad \text{Mev}$$

$$= [0.66525353283 \times 14.3427 \quad \text{Mev}$$

$$= 9.5415 \quad \text{Mev}$$

Increased kinetic energy of the helion-4

$E_{inc} = [E_T - \text{Increased kinetic energy of deuteron}]$

$$= [E_T - [14.3427 - 9.5415] \quad \text{Mev}$$

$$= 4.8012 \text{ Mev}$$

Increased velocity of the deuteron

$$V_{inc} = \sqrt{\frac{2 E_{inc}}{m_d}}$$

$$= \left[\frac{2 \times 9.5415 \times 1.6 \times 10^{-13}}{3.3434 \times 10^{-27}} \right]^{\frac{1}{2}} \quad m/s$$

$$= \left[\frac{30.5328 \times 10^{14}}{3.3434} \right]^{\frac{1}{2}} \quad m/s$$

$$= \left[9.13226057306 \times 10^{14} \right]^{\frac{1}{2}} \quad m/s$$

$$= 3.0219 \times 10^{7} \quad m/s$$

Increased velocity of the helium-4 nucleus

$$V_{inc} = \sqrt{\frac{2 E_{inc}}{m_{He-4}}}$$

$$= \left[\frac{2 \times 4.8012 \times 1.6 \times 10^{-13}}{6.64449 \times 10^{-27}} \right]^{\frac{1}{2}} \quad m/s$$

$$= \left[\frac{15.36384}{6.64449} \times 10^{14} \right]^{\frac{1}{2}} \quad m/s$$

$$= \left[2.3122677586 9 \times 10^{14} \right]^{\frac{1}{2}} \quad m/s$$

$$= [1.5206 \times 10^{7} \quad m/s$$

Angle of propellation

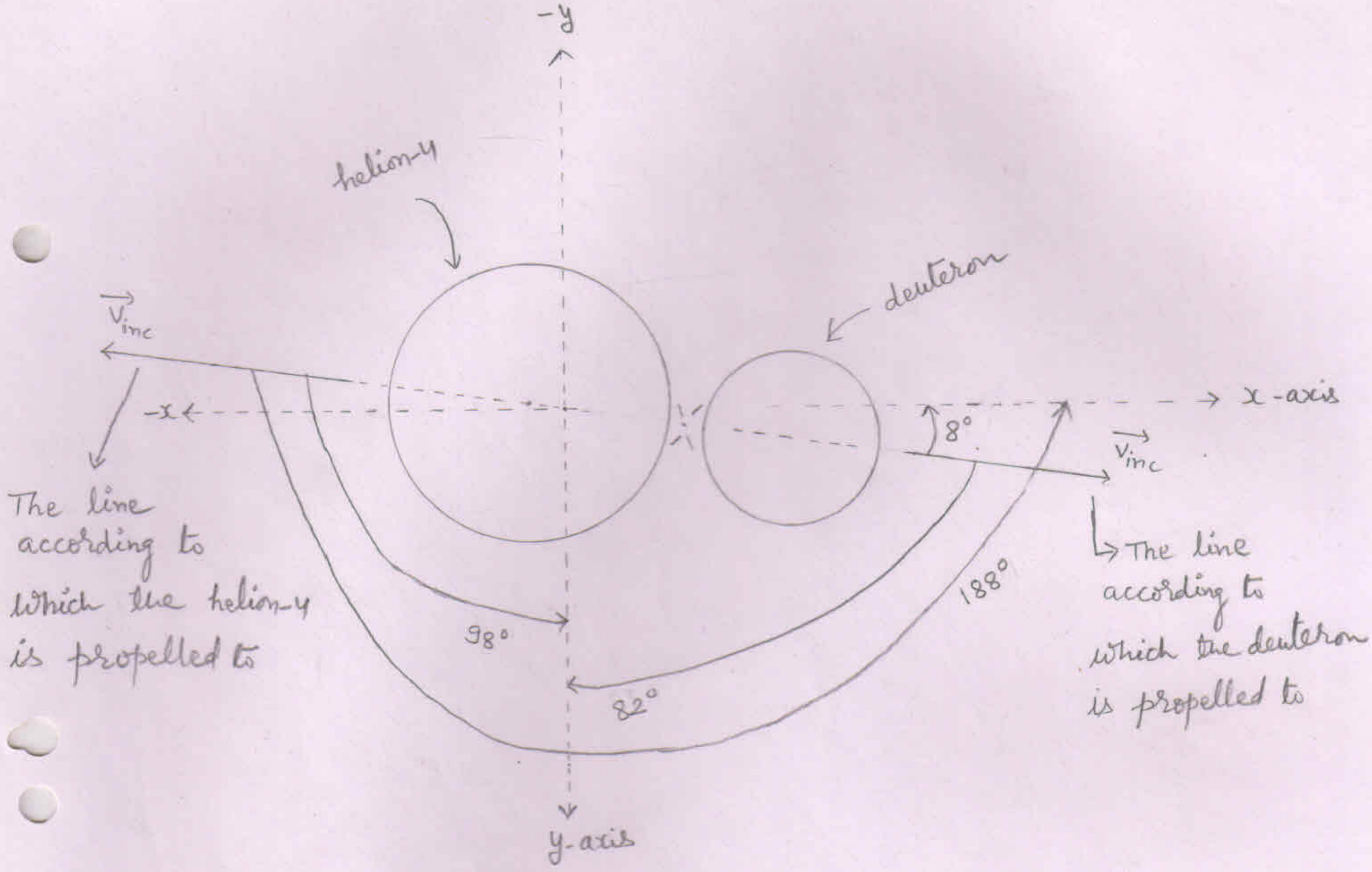
1. As the reduced mass converts into energy, the total energy (E_T) propell both the particles with equal and opposite momentum according to a ray (line) perpendicular to the direction (line) of the velocity of the compound nucleus ($\vec{V}_{CN}$).

2. We know that when there a fusion process occures, then we find the lighter nucleus in the forward direction [or in the direction of ion beam or in the direction of the velocity of the compound nucleus ($\vec{V}_{CN}$)].

3. At point 'F', as $\vec{V}_{CN}$ makes 98° angle with x-axis, 8° angle with y-axis and 90° angle with z-axis.

4. So, the deuteron is propelled making 8° angle with x-axis, 82° angle with y-axis and 90° angle with z-axis.

5. While the helium-4 nucleus is propelled making 188° angle with x-axis, 98° angle with y-axis and 90° angle with z-axis.



Propellation of the produced particles

Components of the increased velocity ($\vec{v}_{inc}$) of the deuteron

1. $\vec{v}_x = v_{inc} \cos\alpha$

$v_{inc} = 3.0219 \times 10^7$ m/s

$\cos\alpha = \cos(8) = 0.99$

$\Rightarrow \vec{v}_x = 3.0219 \times 10^7 \times (0.99)$ m/s

$= 2.9916 \times 10^7$ m/s

2. $\vec{v}_y = v_{inc} \cos\beta$

$\cos\beta = \cos(82) = 0.13$

$\Rightarrow \vec{v}_y = 3.0219 \times 10^7 \times 0.13$ m/s

$= 0.3928 \times 10^7$ m/s

3. $\vec{v}_z = v_{inc} \cos\gamma$

$\cos\gamma = \cos 90^\circ = 0$

$\Rightarrow \vec{v}_z = 3.0219 \times 10^7 \times 0$ m/s $= 0$ m/s

Components of the increased velocity ($\vec{v}_{inc}$) of the helion-4

1. $\vec{v}_x = v_{inc} \cos\alpha$

$v_{inc} = 1.5206 \times 10^7$ m/s

$\cos\alpha = \cos(188) = -\cos(8) = -0.99$

$\Rightarrow \vec{v}_x = 1.5206 \times 10^7 \times (-0.99)$ m/s

$= -1.5053 \times 10^7$ m/s

2. $\vec{v}_y = v_{inc} \cos\beta$

$\cos\beta = \cos(98) = -\cos(82) = -0.13$

$\Rightarrow \vec{v}_y = 1.5206 \times 10^7 \times (-0.13)$ m/s

$= -0.1976 \times 10^7$ m/s

3. $\vec{v}_z = v_{inc} \cos\gamma$

$\cos\gamma = \cos 90^\circ = 0$

$\Rightarrow \vec{v}_z = 1.5206 \times 10^7 \times 0$ m/s $= 0$ m/s

Components of the final velocity ($\vec{v}_f$) of the particles

I. For deuteron

According to	Inhereted velocity ($\vec{v}_{inh}$)	Increased velocity ($\vec{v}_{inc}$)	Final velocity ($\vec{v}_f$) $\vec{v}_f = \vec{v}_{inh} + \vec{v}_{inc}$
x-axis	$\vec{v}_x = -0.1130 \times 10^7$ m/s	$\vec{v}_x = 2.9916 \times 10^7$ m/s	$\vec{v}_x = 2.8786 \times 10^7$ m/s
y-axis	$\vec{v}_y = 0.8098 \times 10^7$ m/s	$\vec{v}_y = 0.3928 \times 10^7$ m/s	$\vec{v}_y = 1.2026 \times 10^7$ m/s
z-axis	$\vec{v}_z = 0$ m/s	$\vec{v}_z = 0$ m/s	$\vec{v}_z = 0$ m/s

II. For helion-4

According to	Inhereted velocity ($\vec{v}_{inh}$)	Increased velocity ($\vec{v}_{inc}$)	Final velocity ($\vec{v}_f$) $\vec{v}_f = \vec{v}_{inh} + \vec{v}_{inc}$
x-axis	$\vec{v}_x = -0.1130 \times 10^7$ m/s	$\vec{v}_x = -1.5053 \times 10^7$ m/s	$\vec{v}_x = -1.6183 \times 10^7$ m/s
y-axis	$\vec{v}_y = 0.8098 \times 10^7$ m/s	$\vec{v}_y = -0.1976 \times 10^7$ m/s	$\vec{v}_y = 0.6122 \times 10^7$ m/s
z-axis	$\vec{v}_z = 0$ m/s	$\vec{v}_z = 0$ m/s	$\vec{v}_z = 0$ m/s

Final velocity of the deuteron

$$v_f^2 = v_x^2 + v_y^2 + v_z^2$$

$v_x = 2.8786 \times 10^7$ m/s
$v_y = 1.2026 \times 10^7$ m/s
$v_z = 0$ m/s

$$\Rightarrow v_f^2 = (2.8786 \times 10^7)^2 + (1.2026 \times 10^7)^2 + (0)^2 \ m^2/s^2$$

$$\Rightarrow v_f^2 = (8.28633796 \times 10^{14}) + (1.44624676 \times 10^{14}) + (0) \ m^2/s^2$$

$$\Rightarrow v_f^2 = 9.73258472 \times 10^{14} \ m^2/s^2$$

$$\Rightarrow v_f = 3.1197 \times 10^7 \ m/s$$

Final kinetic energy of the deuteron

$$E = \frac{1}{2} m_d v_f^2$$

$v_f^2 = 9.73258472 \times 10^{14} \ m^2/s^2$

$$\Rightarrow E = \frac{1}{2} \times 3.3434 \times 10^{-27} \times 9.73258472 \times 10^{14} \ J$$

$$= 16.2699618764 \times 10^{-13} \ J$$

$$= 10.1687 \ MeV$$

$$\Rightarrow m_d v_f^2 = 3.3434 \times 10^{-27} \times 9.73258472 \times 10^{14} \ J$$

$$= 32.5399 \times 10^{-13} \ J$$

Acting forces on the deuteron

1. $F_y = q V_x B_z \sin\theta$

$\vec{V}_x = 2.8786 \times 10^7$ m/s
$\vec{B}_z = -1$ Tesla
$q = 1.6 \times 10^{-19}$ C
$\sin\theta = \sin 90° = 1$

$\Rightarrow F_y = 1.6 \times 10^{-19} \times 2.8786 \times 10^7 \times 1 \times 1$ N
$= 4.6057 \times 10^{-12}$ N

From the right hand palm rule, the direction of force $\vec{F}_y$ is according to $-y$ axis. So,

$$\vec{F}_y = -4.6057 \times 10^{-12} \text{ N}$$

2. $F_z = q V_x B_y \sin\theta$

$\vec{B}_y = 1$ Tesla
$\sin\theta = \sin 90° = 1$

$\Rightarrow F_z = 1.6 \times 10^{-19} \times 2.8786 \times 10^7 \times 1 \times 1$ N
$= 4.6057 \times 10^{-12}$ N

From the right hand palm rule, the direction of force $\vec{F}_z$ is according to $-z$ axis. So,

$$\vec{F}_z = -4.6057 \times 10^{-12} \text{ N}$$

3. $F_x = q V_y B_z \sin\theta$

$\vec{V}_y = 1.2026 \times 10^7$ m/s
$\vec{B}_z = -1$ Tesla
$\sin\theta = \sin 90° = 1$

$\Rightarrow F_x = 1.6 \times 10^{-19} \times 1.2026 \times 10^7 \times 1 \times 1$ N
$= 1.9241 \times 10^{-12}$ N

From the right hand palm rule, the direction of force $\vec{F}_x$ is according to $+x$ axis. So,

4. Resultant force (F_R) :

$$F_R^2 = F_x^2 + F_y^2 + F_z^2$$

$$F_x = 1.9241 \times 10^{-12} \ N$$

$$F = F_y = F_z = 4.6057 \times 10^{-12} \ N$$

$$\Rightarrow F_R^2 = F_x^2 + 2F^2$$

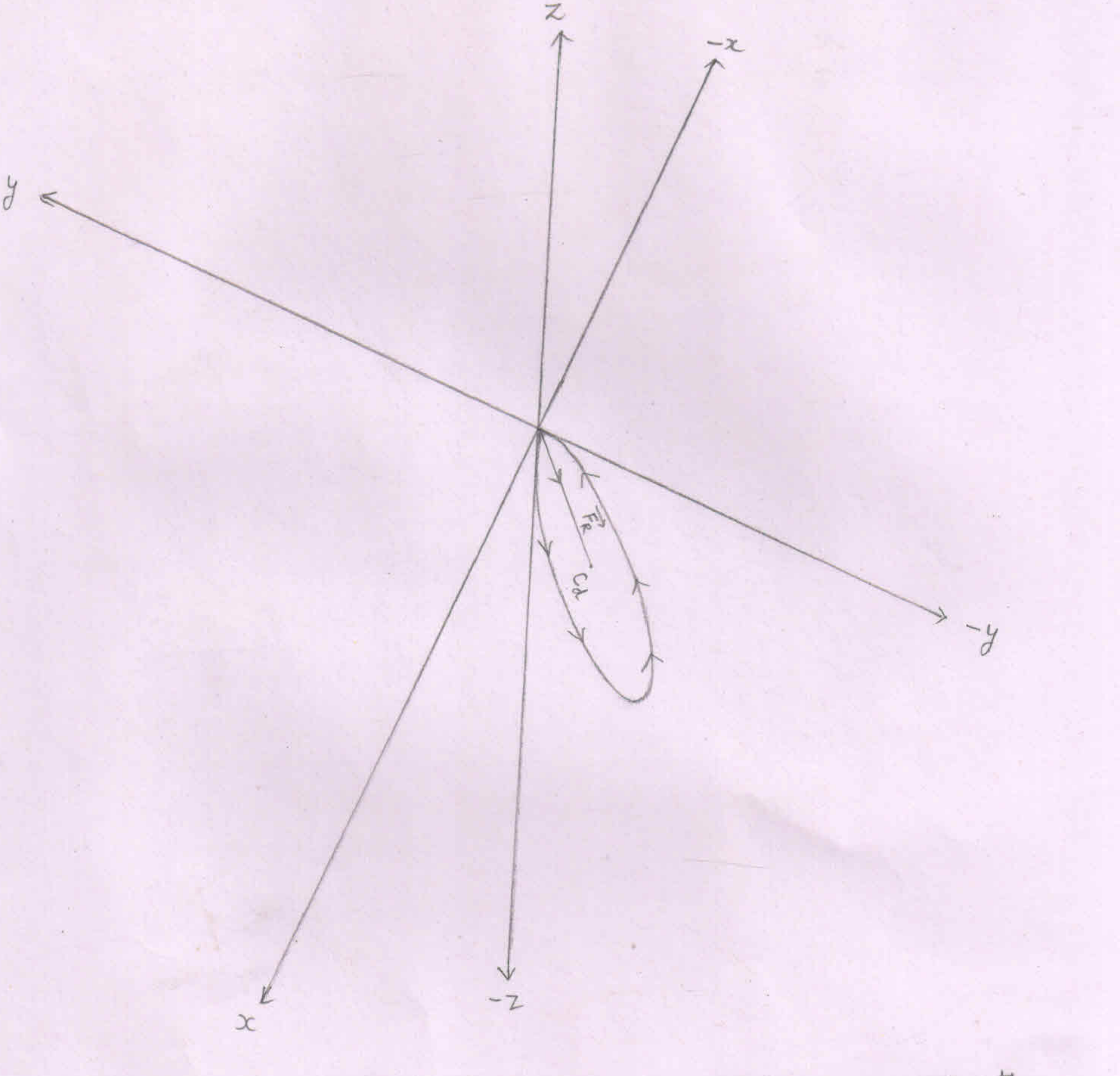
$$\Rightarrow F_R^2 = (1.9241 \times 10^{-12})^2 + 2(4.6057 \times 10^{-12})^2 \ N^2$$

$$\Rightarrow F_R^2 = (3.70216081 \times 10^{-24}) + 2(21.21247249 \times 10^{-24}) \ N^2$$

$$\Rightarrow F_R^2 = (3.70216081 \times 10^{-24}) + (42.42494498 \times 10^{-24}) \ N^2$$

$$\Rightarrow F_R^2 = 46.12710579 \times 10^{-24} \ N^2$$

$$\Rightarrow F_R = 6.7916 \times 10^{-12} \ N$$



⇒ The circular orbit to be followed by the deuteron lies in the IV (down) quadrant made up of the positive x axis, negative y axis and the negative z axis.

⇒ C_d = centre of the circle to be followed by the deuteron

Angles that make the resultant force ($\vec{F_R}$) [acting on the deuteron when the deuteron is at point 'F'] with positive x, y and z-axes.

1. With x-axis

$$\cos\alpha = \frac{F_R \cos\alpha}{F_R} = \frac{\vec{F_x}}{F_R} = \frac{1.9241 \times 10^{-12}}{6.7916 \times 10^{-12}} \frac{N}{N}$$

$\Rightarrow \cos\alpha = 0.2833$

$\Rightarrow \alpha \simeq 73.6$ degree $[\because \cos(73.6) = 0.2823]$

2. With y-axis

$$\cos\beta = \frac{F_R \cos\beta}{F_R} = \frac{\vec{F_y}}{F_R} = \frac{-4.6057 \times 10^{-12}}{6.7916 \times 10^{-12}} \frac{N}{N}$$

$\Rightarrow \cos\beta = -0.6781$

$\Rightarrow \beta \simeq 132.6$ degree $[\because \cos(132.6) = -0.6768]$

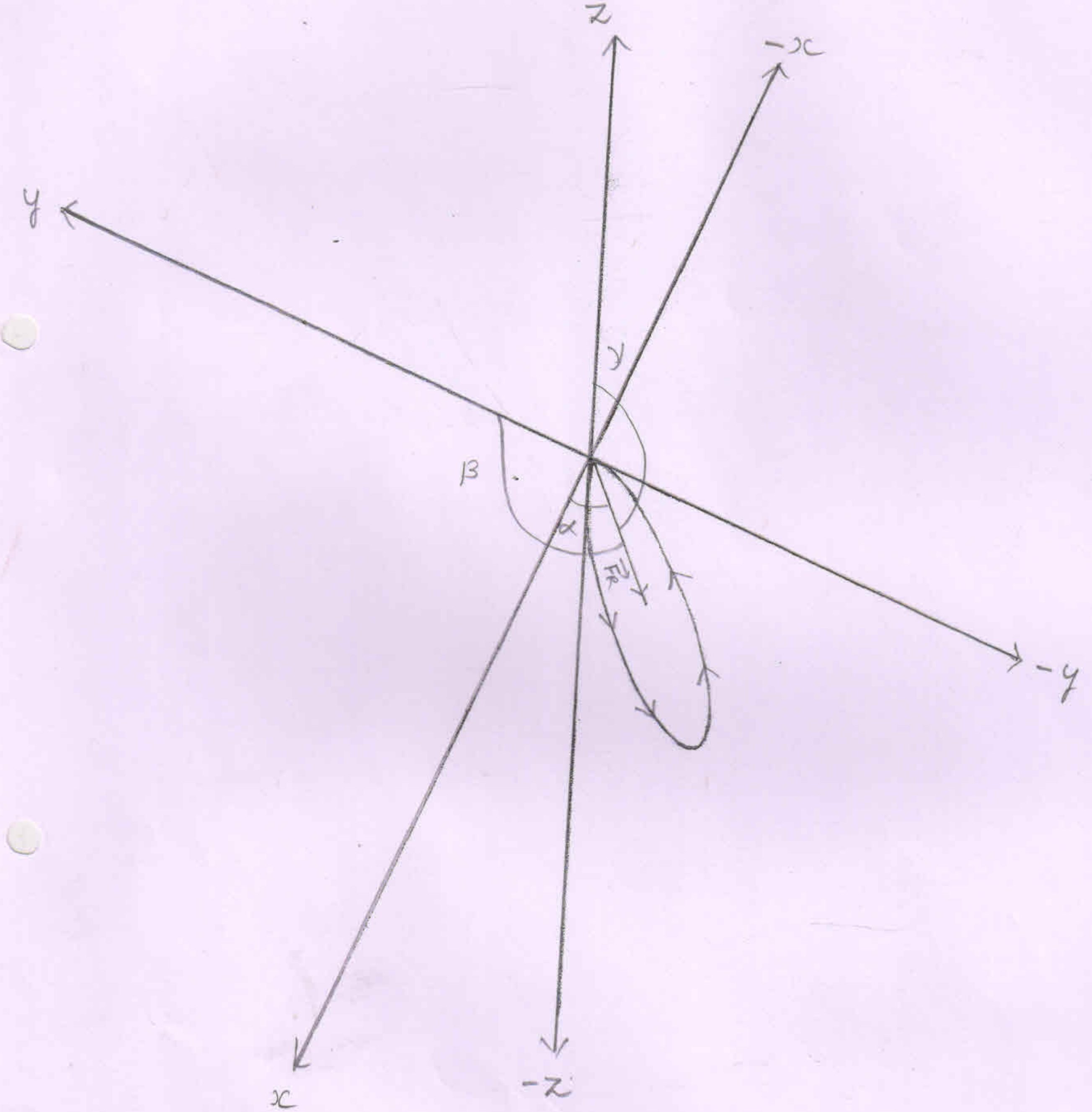
3. With z-axis

$$\cos\gamma = \frac{F_R \cos\gamma}{F_R} = \frac{\vec{F_z}}{F_R} = \frac{-4.6057 \times 10^{-12}}{6.7916 \times 10^{-12}} \frac{N}{N}$$

$\Rightarrow \cos\gamma = -0.6781$

$\Rightarrow \gamma \simeq 132.6$ degree

Angles that make the resultant force ($\vec{F_R}$) at point F with the positive x, y and z axes.



where,

$\alpha \simeq 73.6$

$\beta \simeq 132.6$

$\gamma \simeq 132.6$

5. Radius of the circular orbit followed by the deuteron :-

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

$mv^2 = 32.5399 \times 10^{-13}$ J

$F_R = 6.7916 \times 10^{-12}$ N

$$\Rightarrow r = \frac{32.5399 \times 10^{-13}}{6.7916 \times 10^{-12}} \text{ m}$$

$$\Rightarrow r = 4.79119 \times 10^{-1} \text{ m}$$

$$\Rightarrow r = 47.9119 \times 10^{-2} \text{ m}$$