

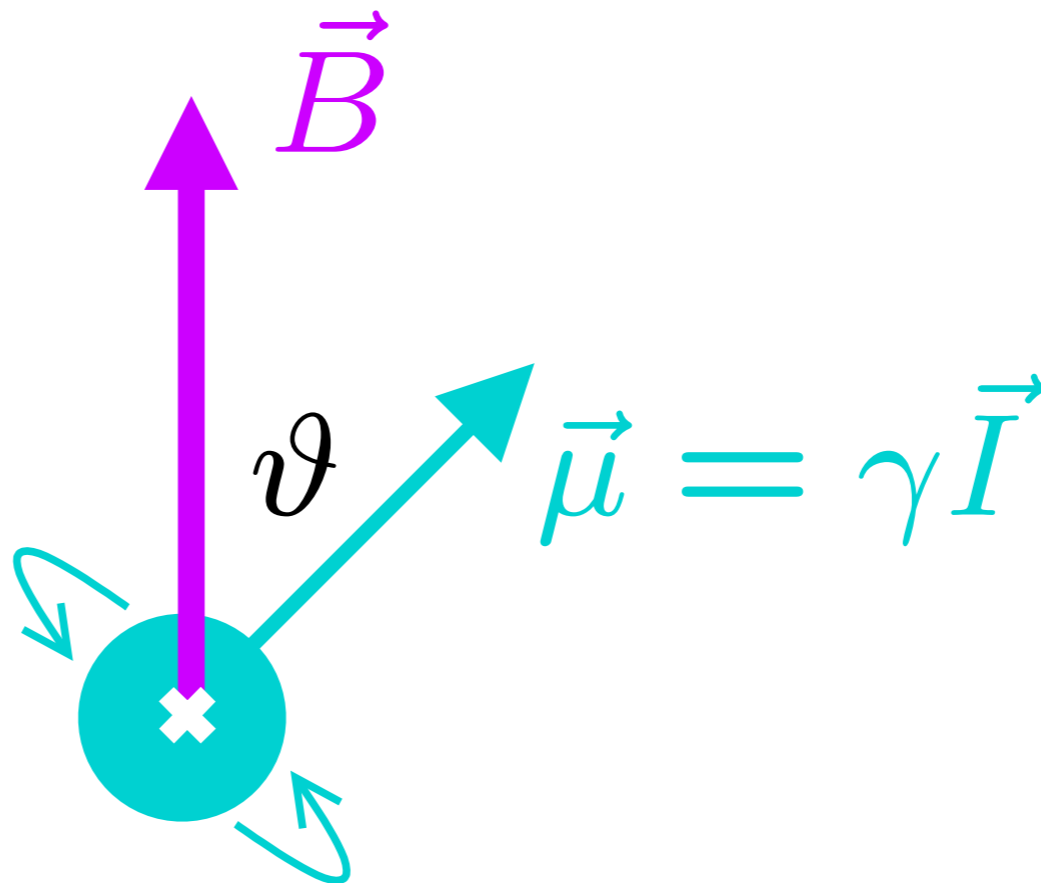
# Lecture 1: Nuclear magnetic resonance

# Magnetic moment

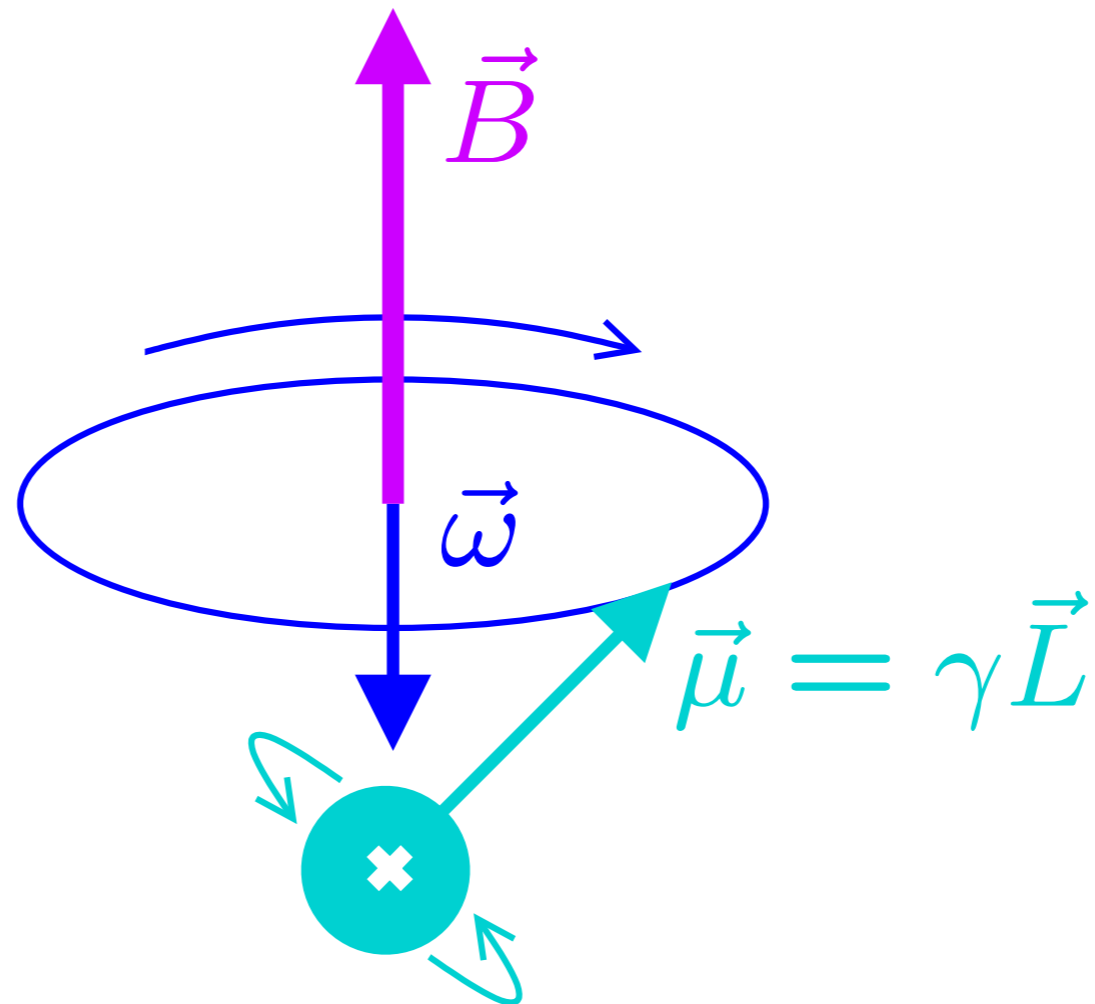
$$\vec{\mu} = \gamma \vec{I}$$

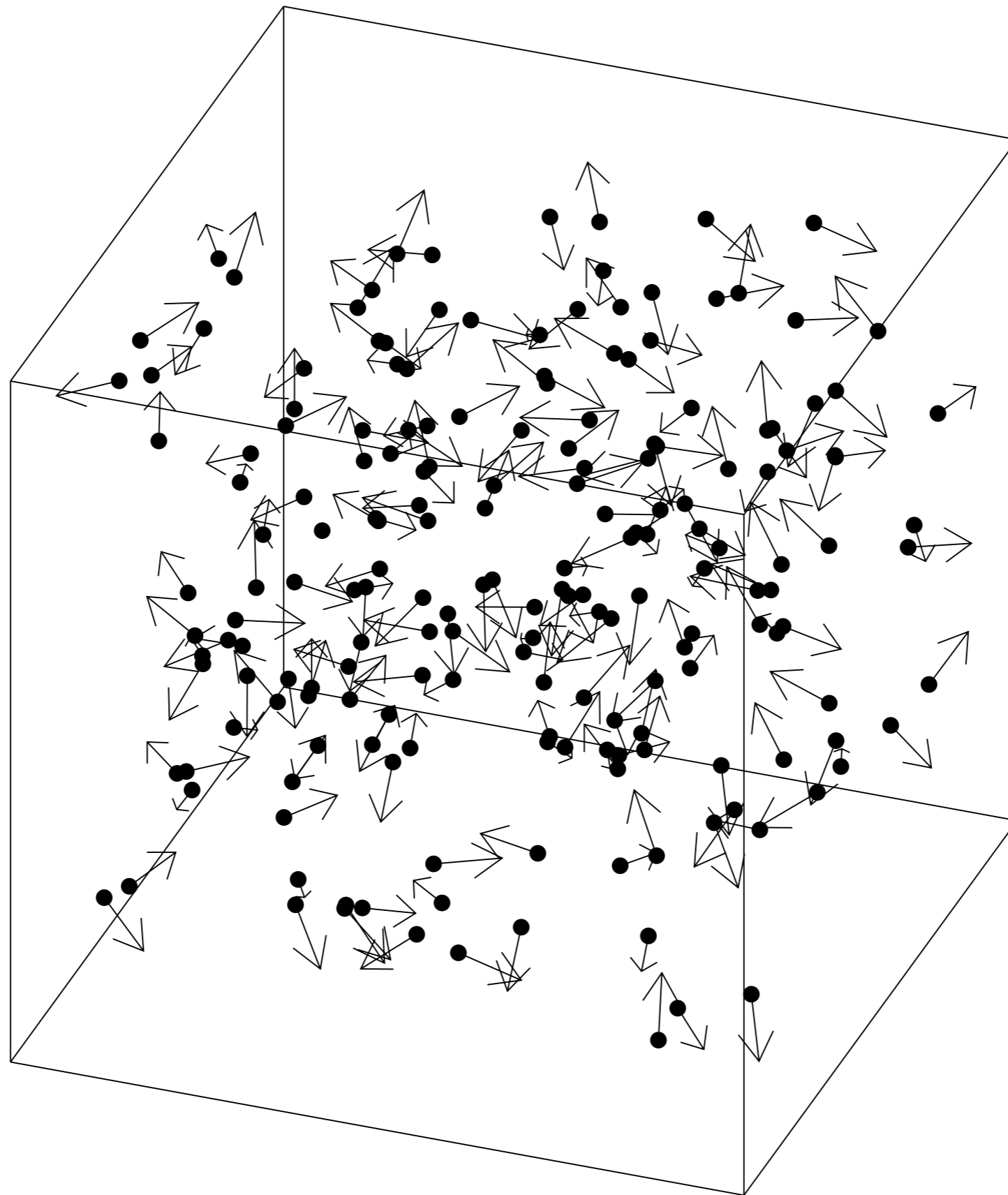
## Energy

$$E = -\vec{\mu} \cdot \vec{B} = -|\mu||B| \cos \theta$$

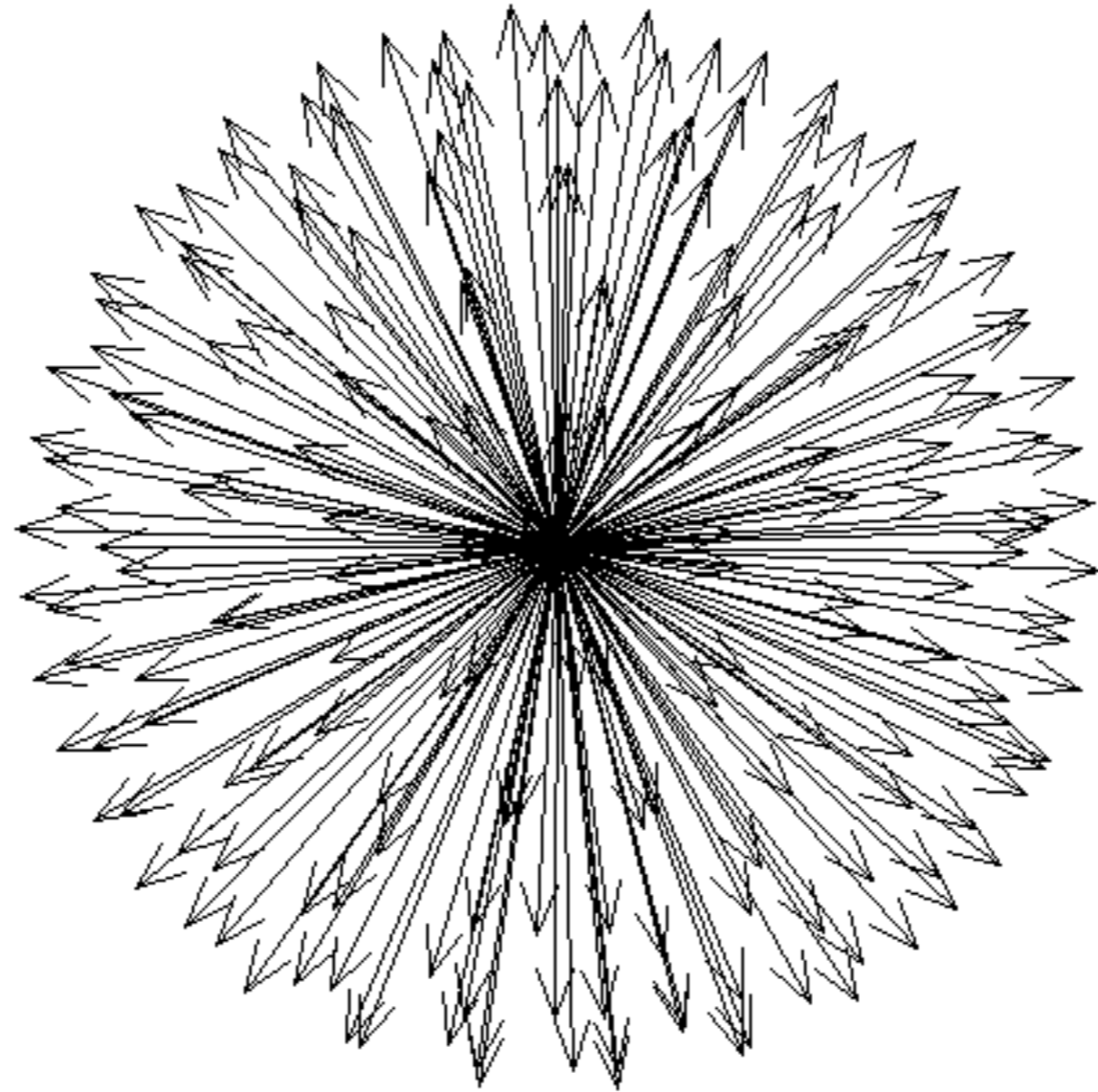


Angular precession frequency  $\vec{\omega} = -\gamma \vec{B}$

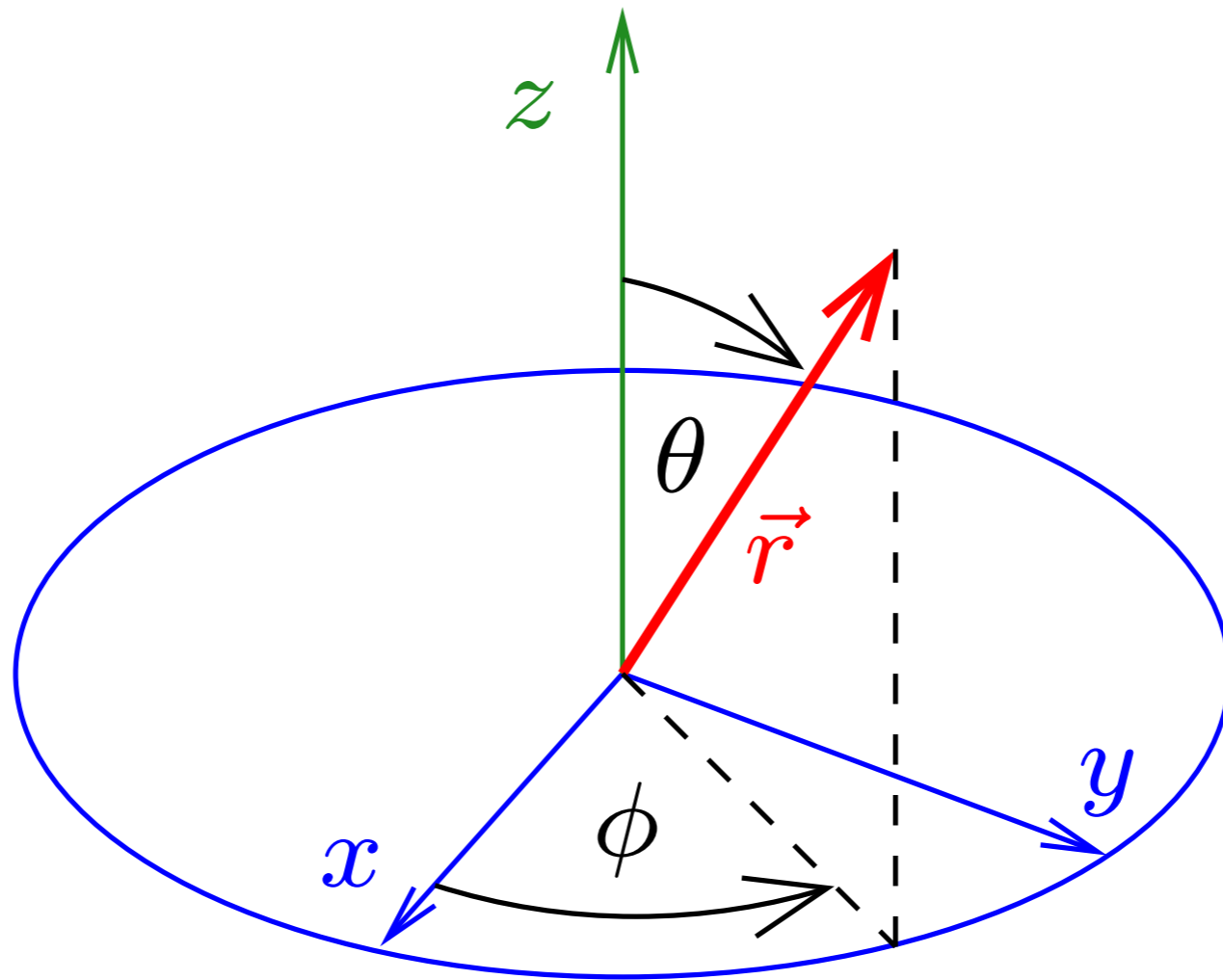


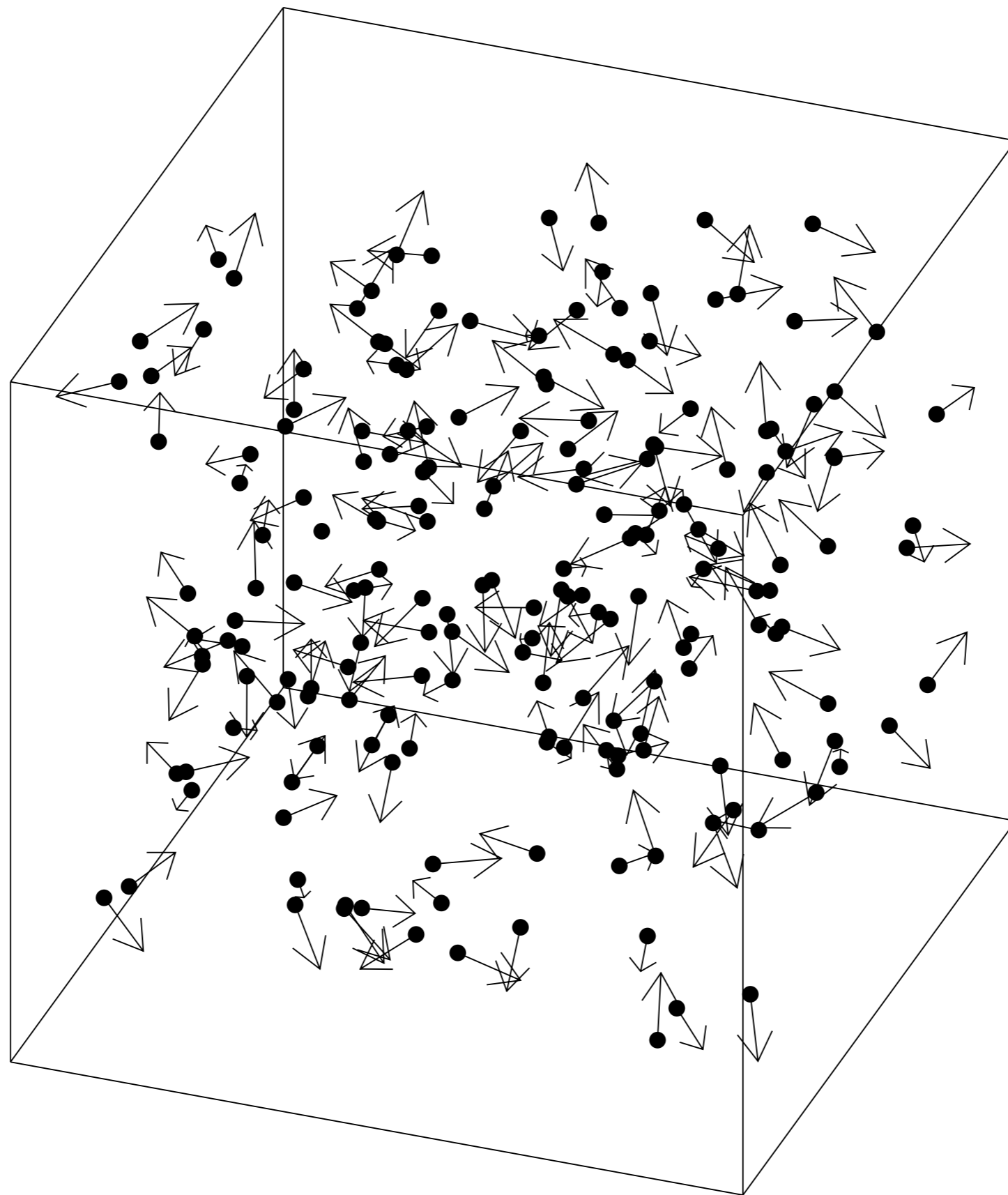


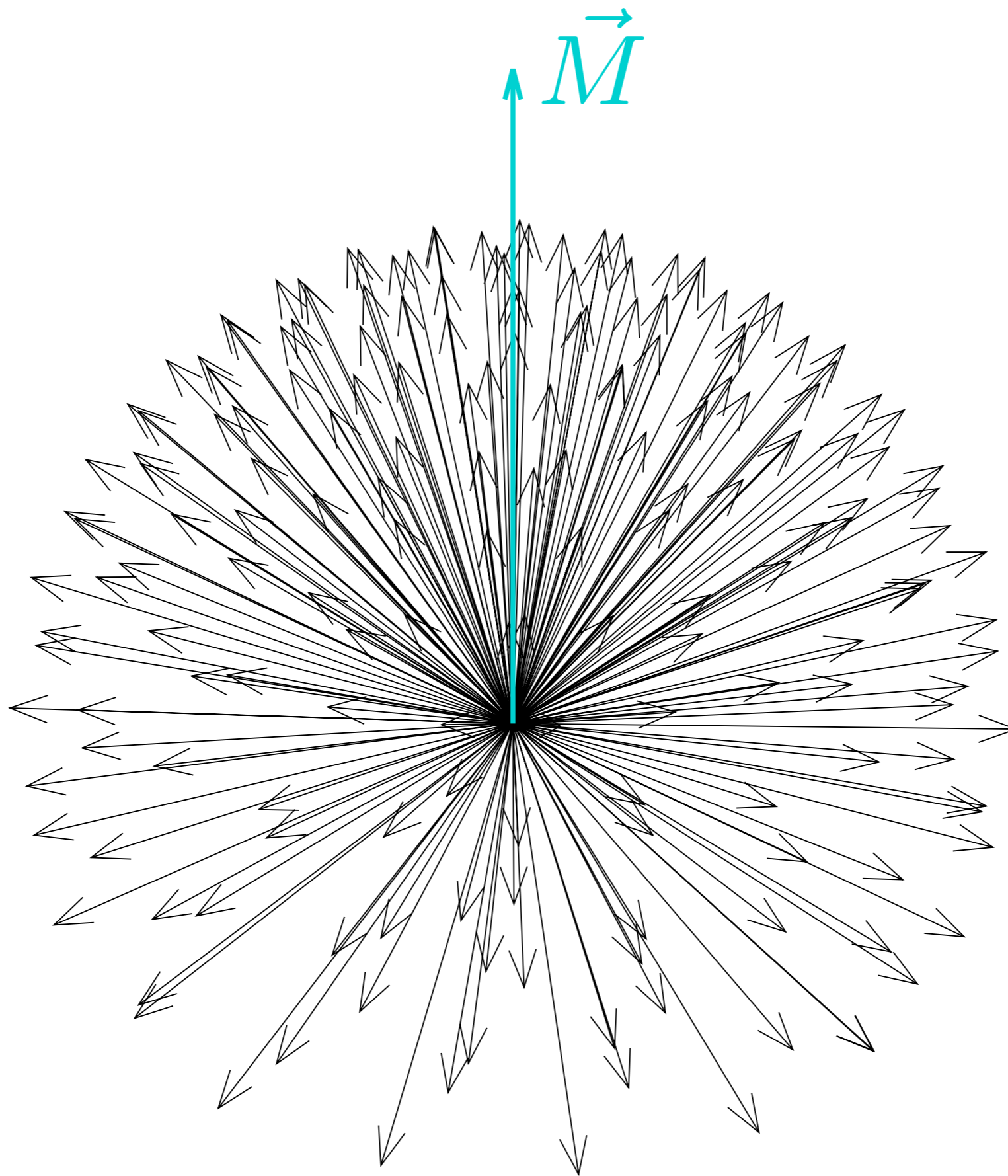
$$\vec{M} = (\vec{\mu}_1 + \vec{\mu}_2 + \vec{\mu}_3 + \vec{\mu}_4 + \vec{\mu}_5 + \vec{\mu}_6 + \dots) / V \quad \text{Magnetization}$$



# Spherical coordinates

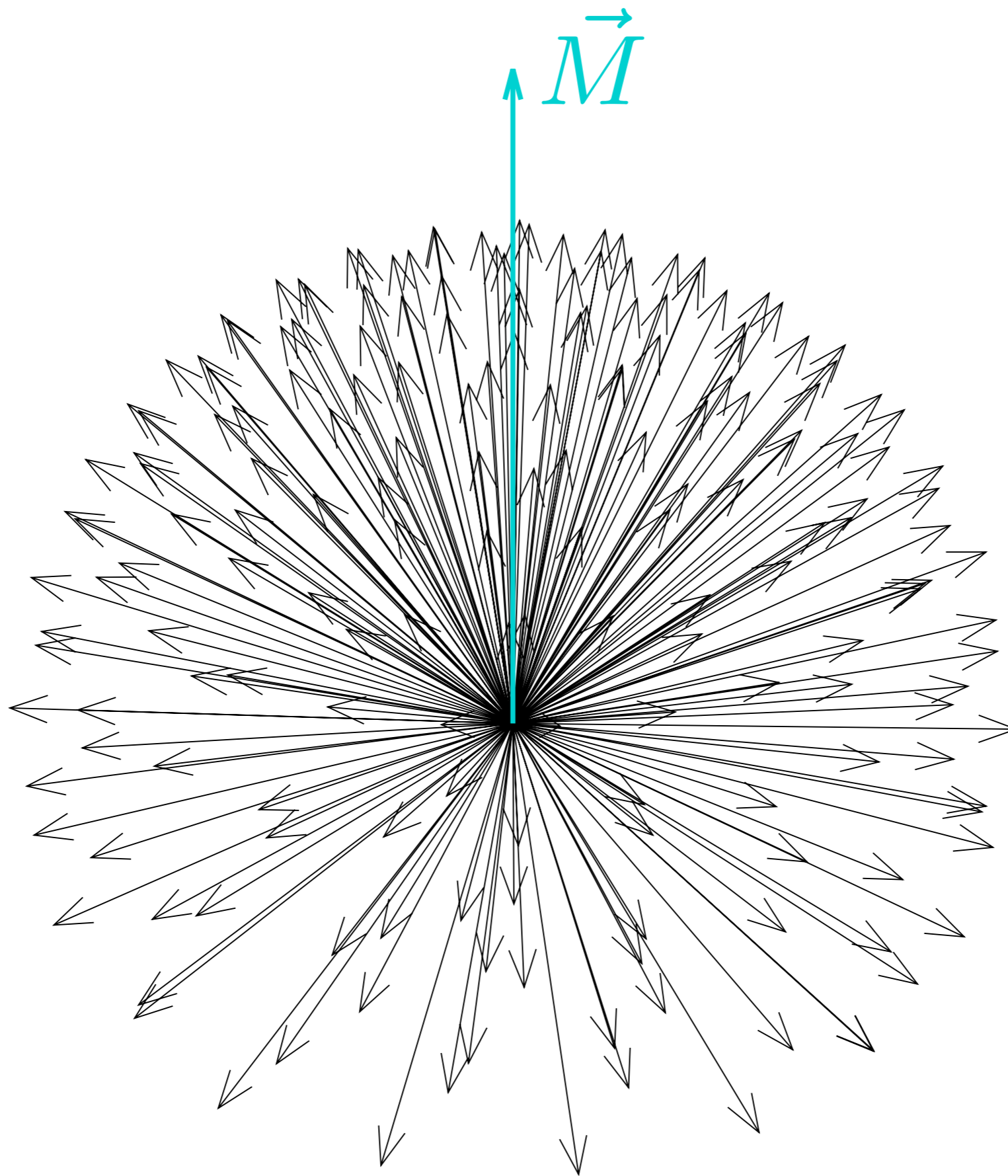


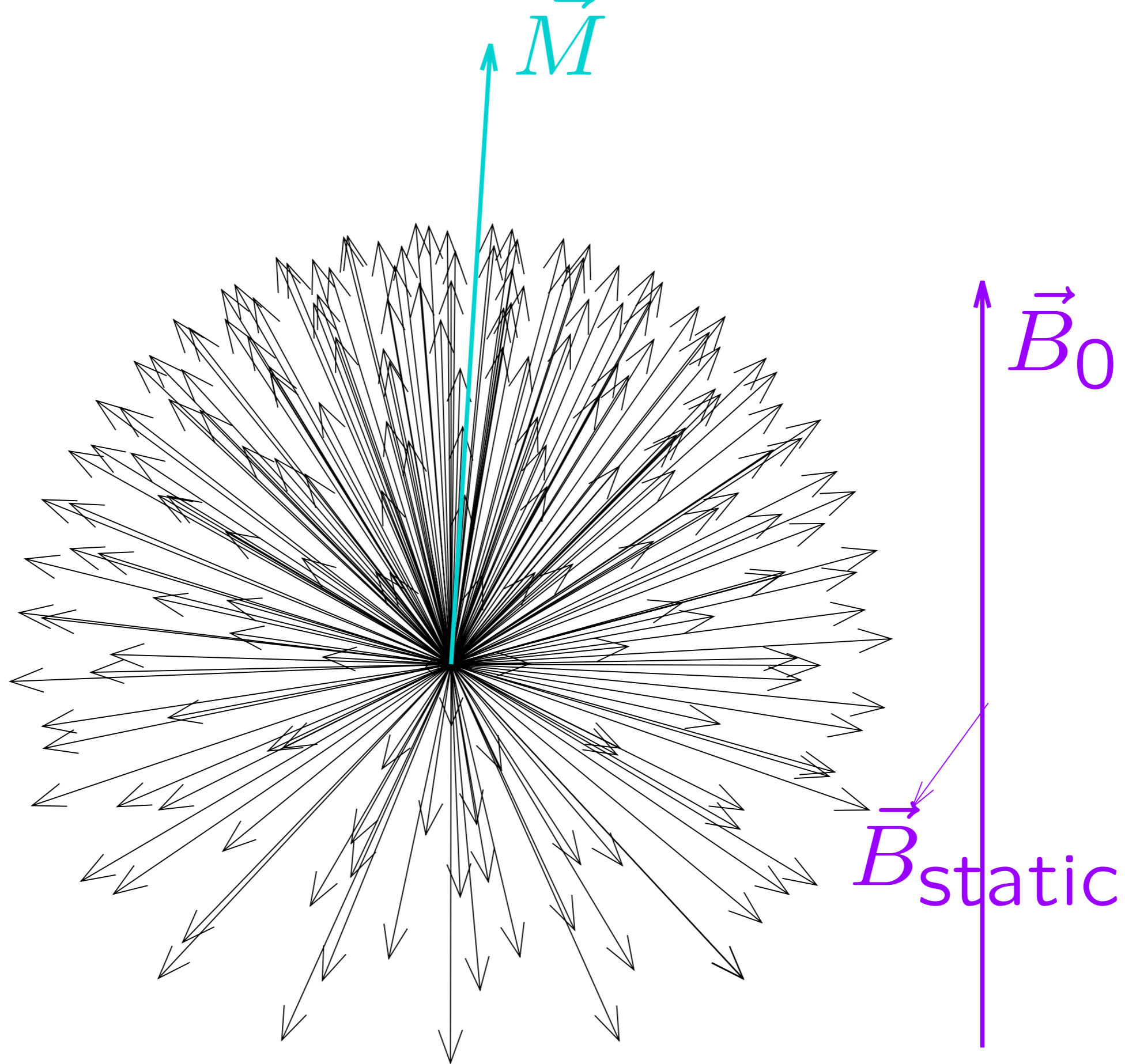


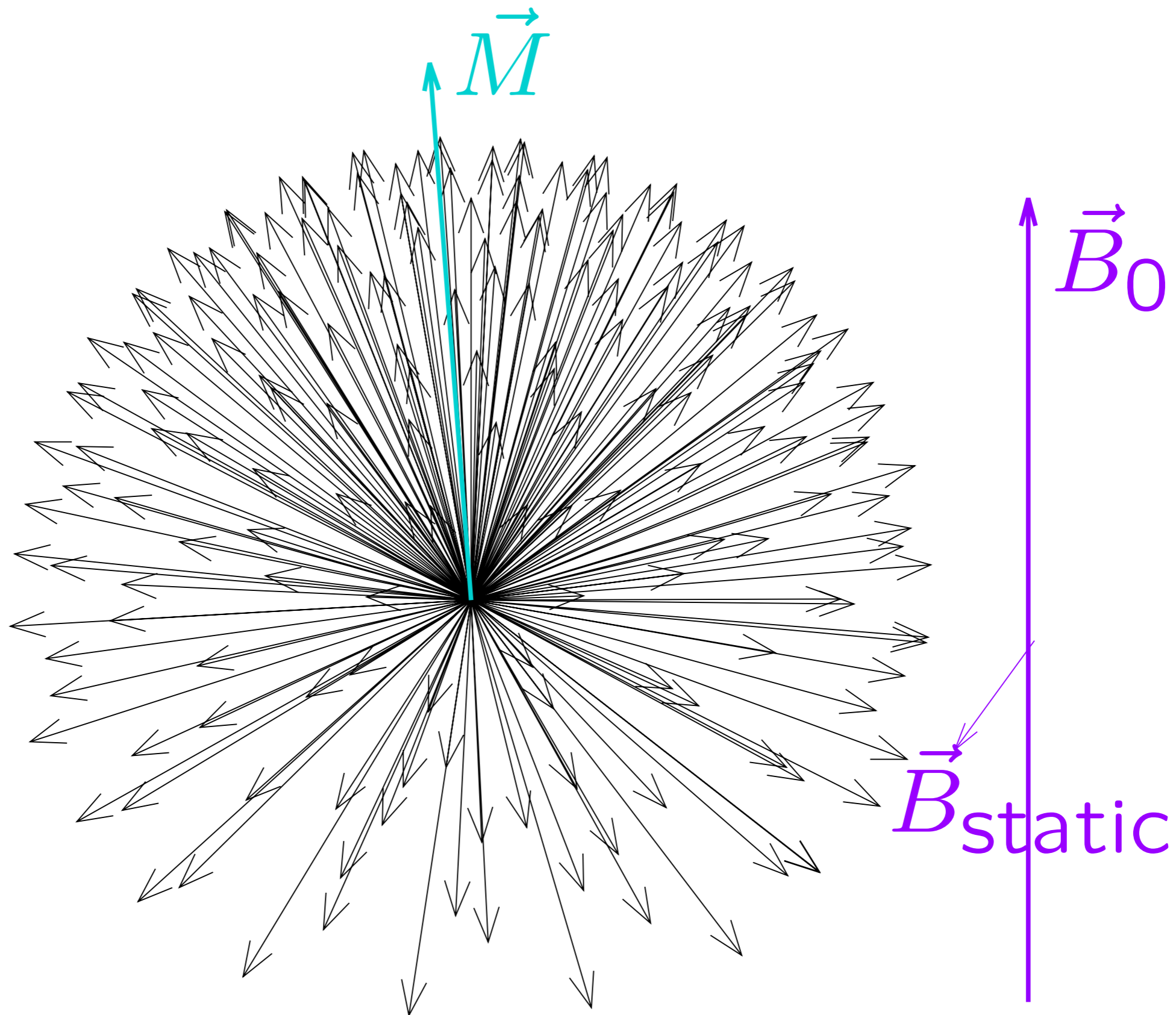


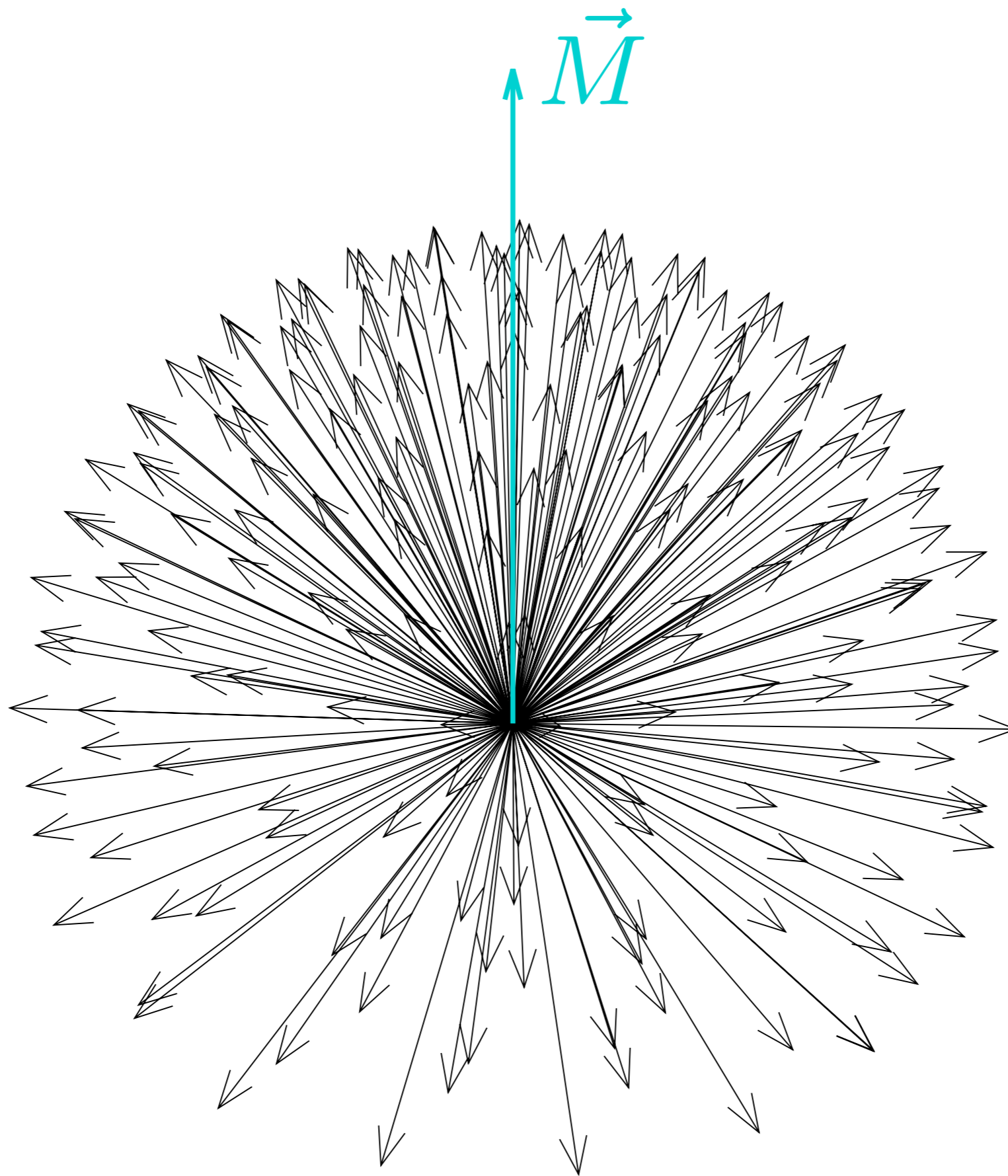


Longitudinal polarization

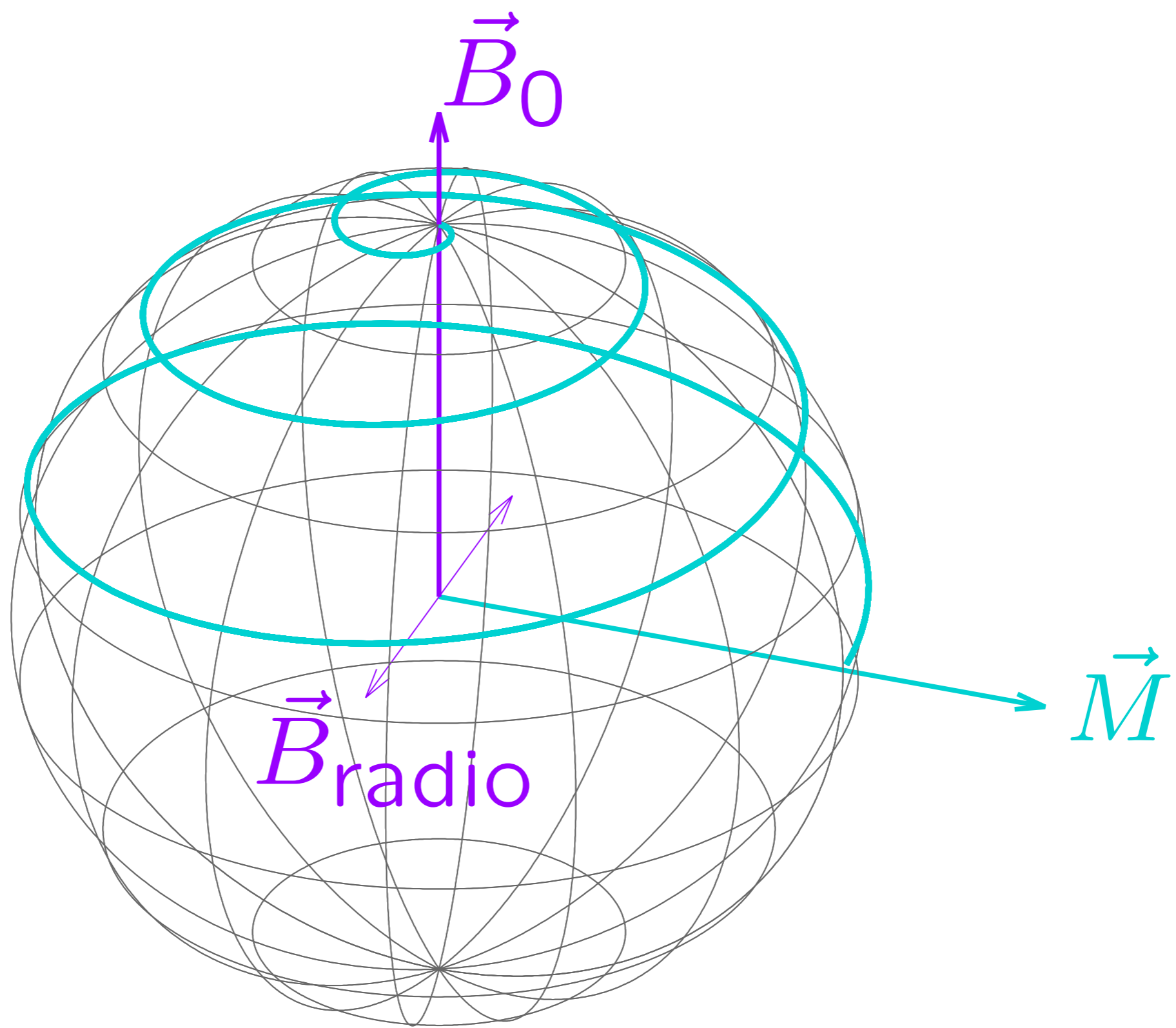


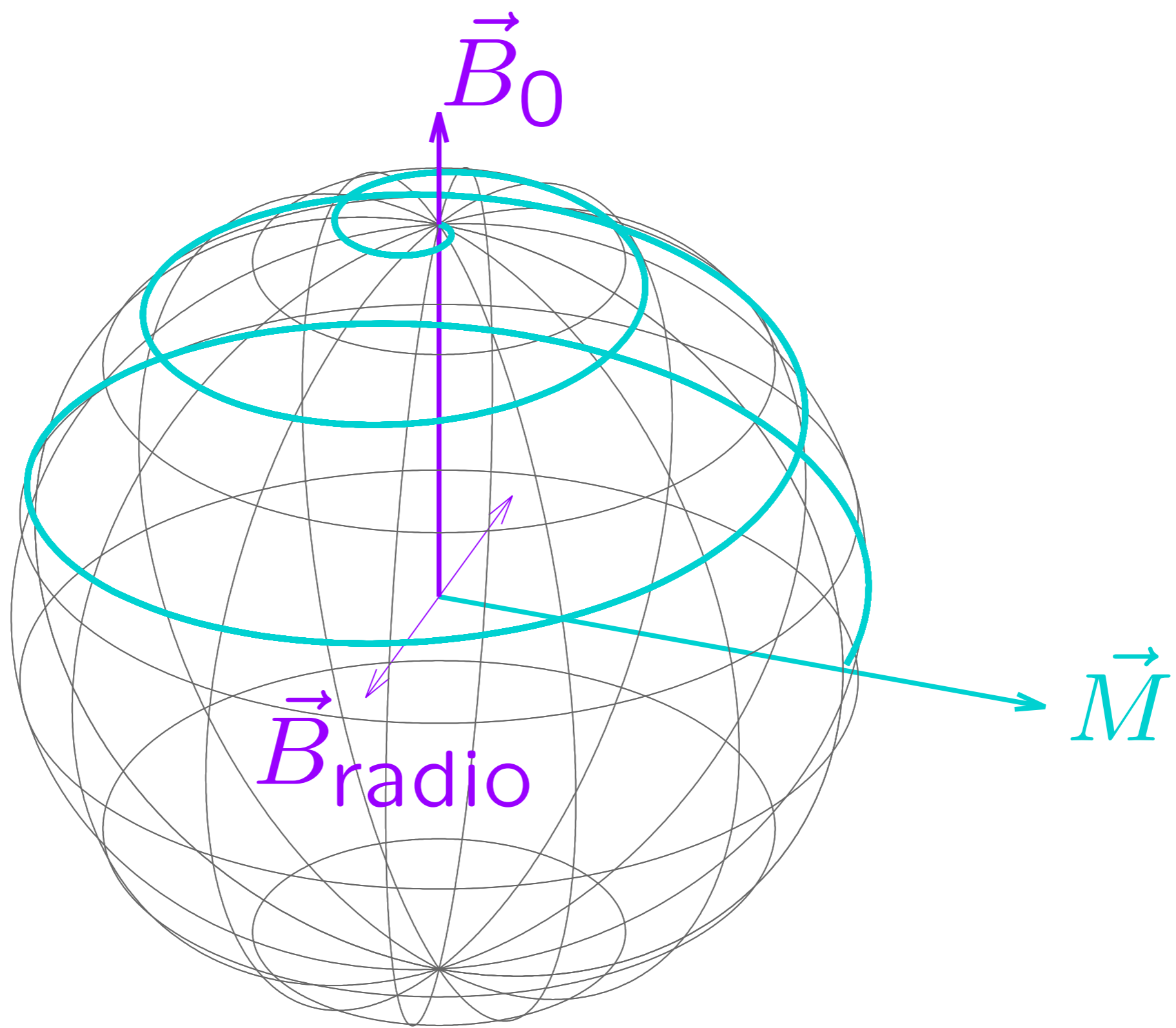




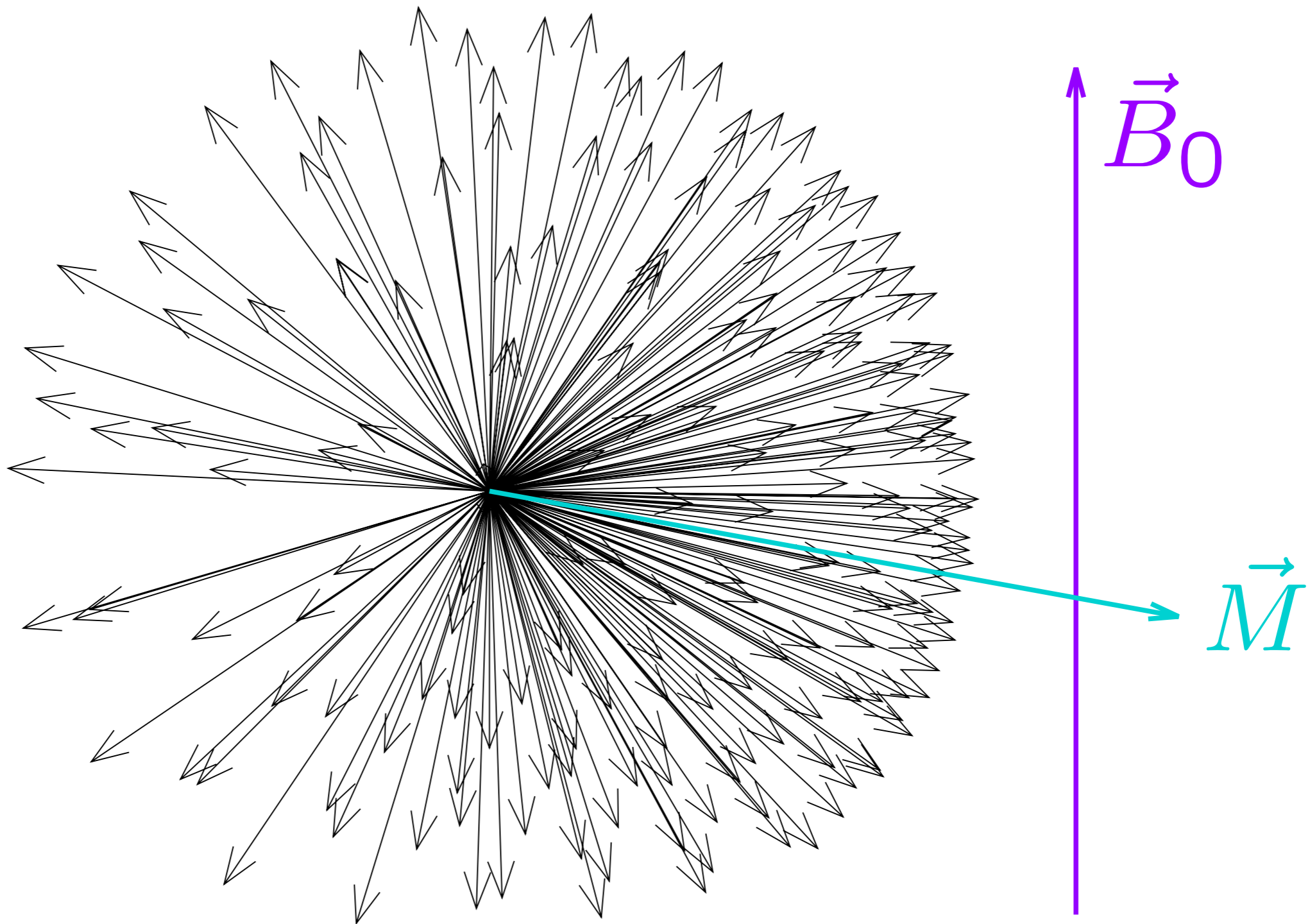


Flipping magnetization

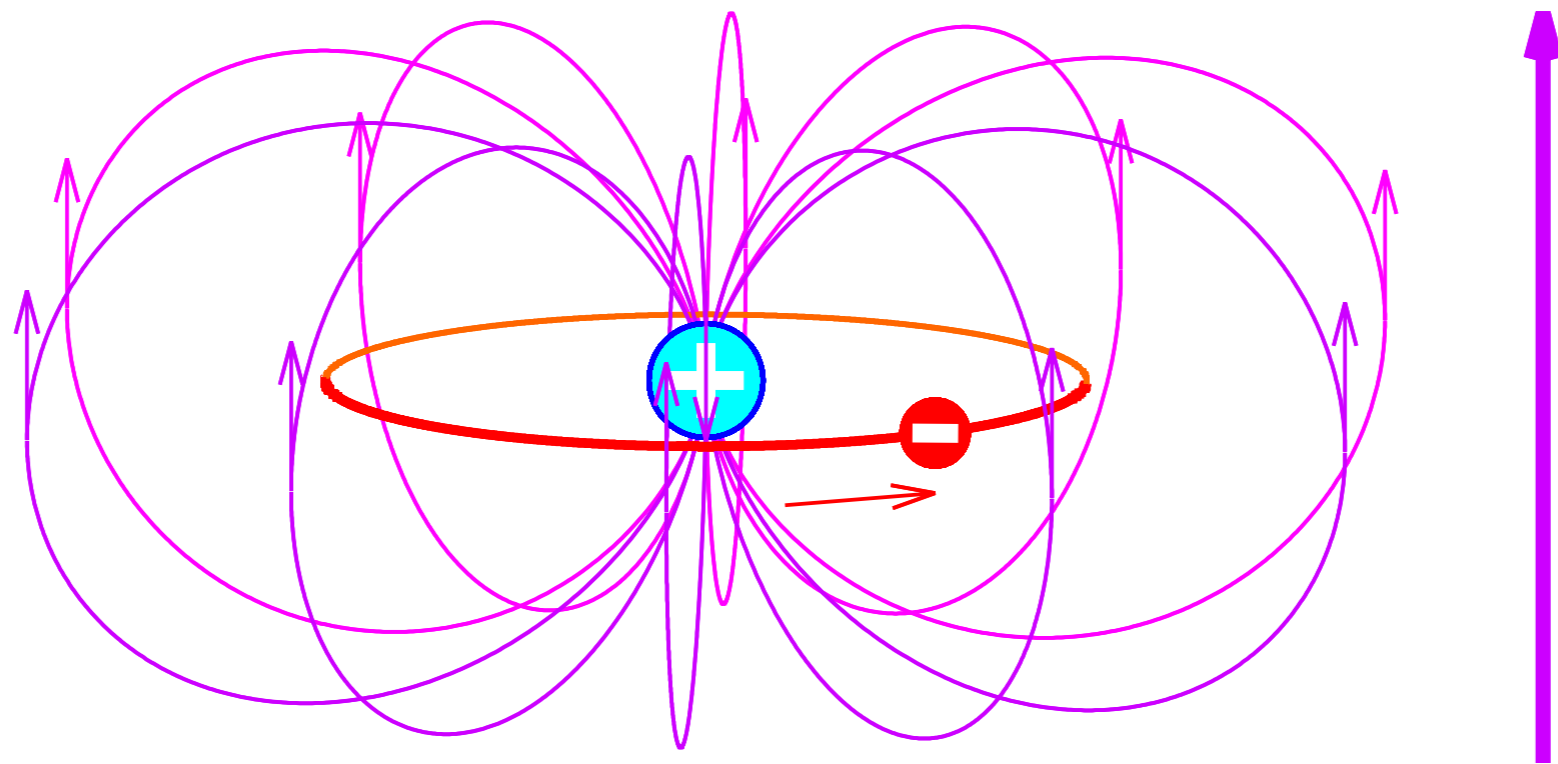


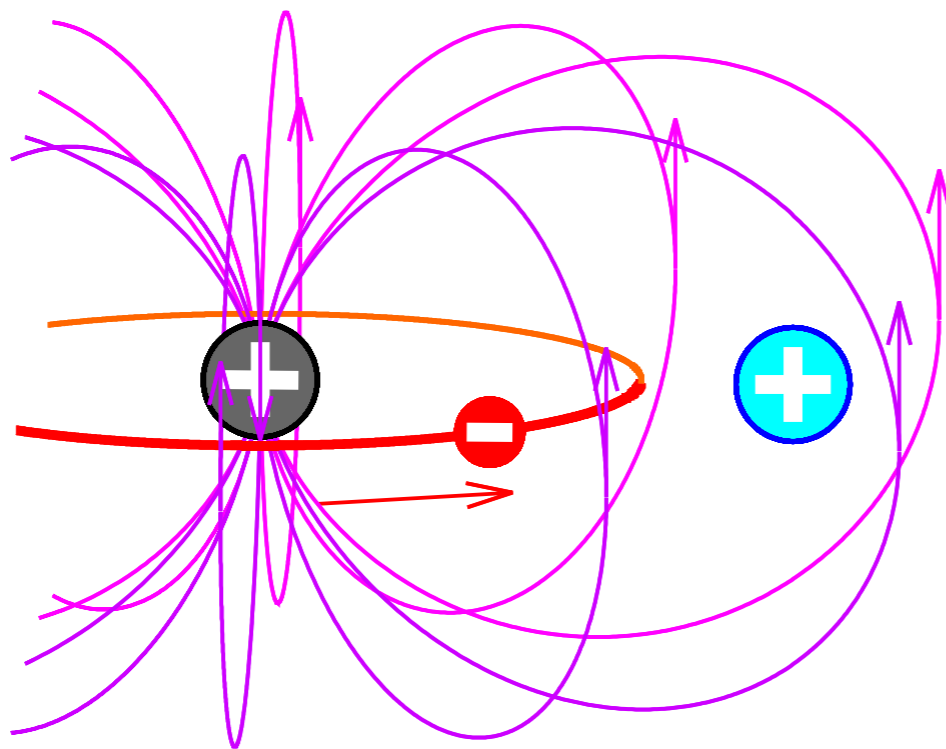




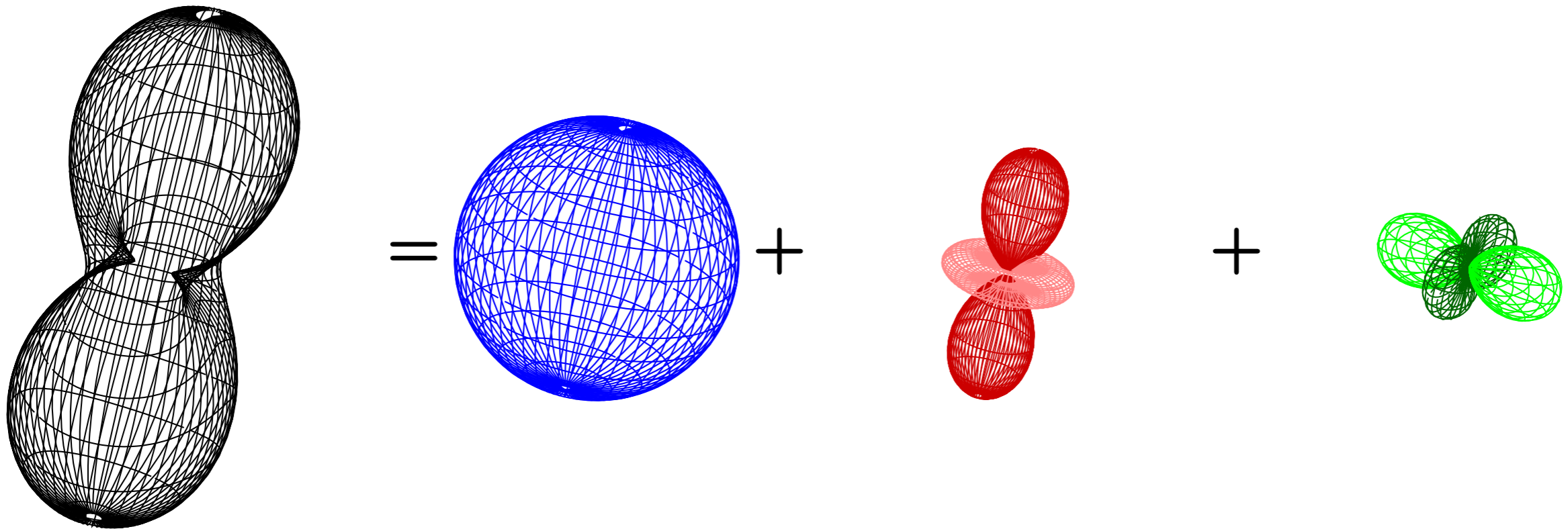


Transverse polarization





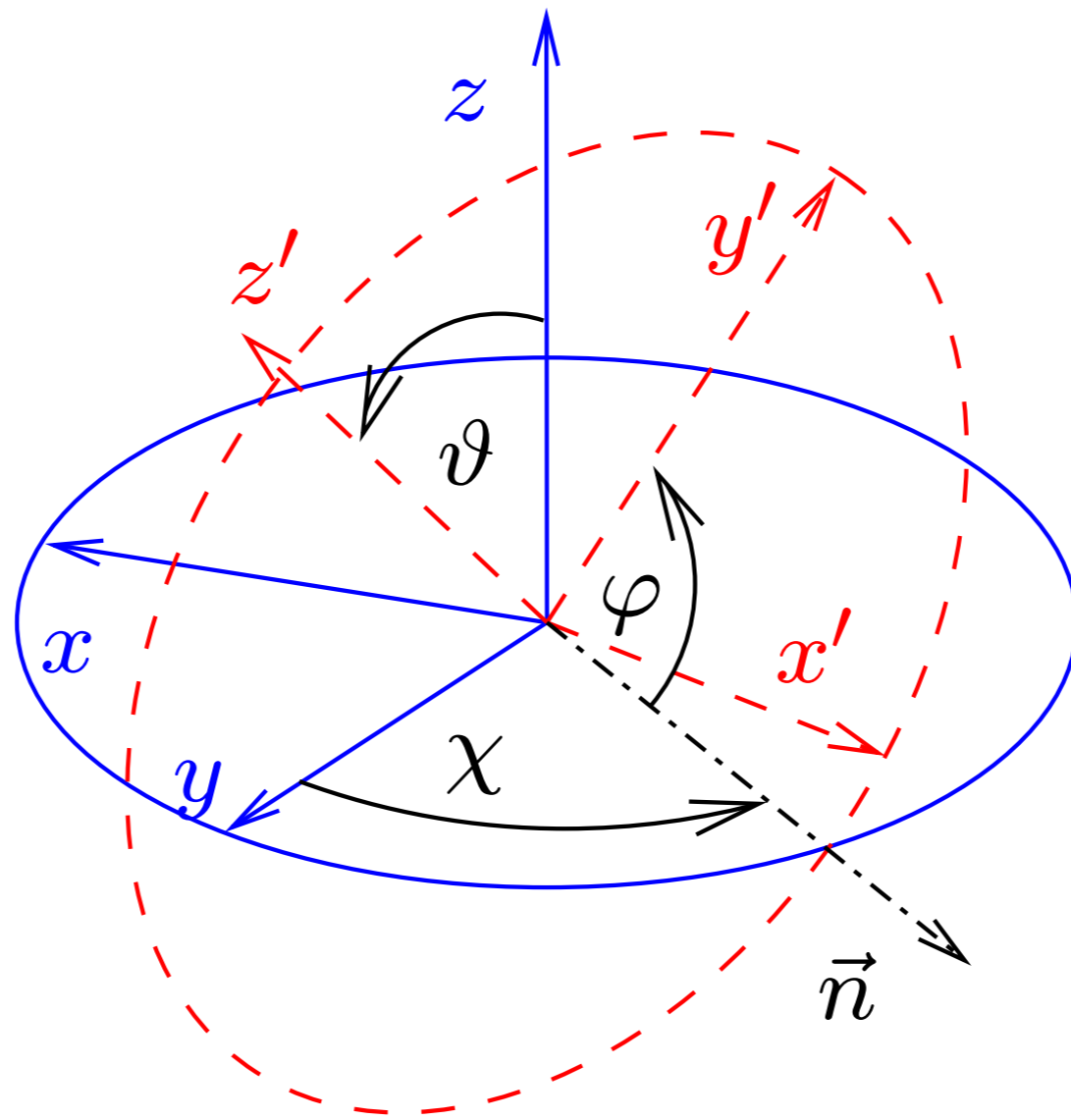
$$\begin{pmatrix} \delta_{XX} & 0 & 0 \\ 0 & \delta_{YY} & 0 \\ 0 & 0 & \delta_{ZZ} \end{pmatrix} = \delta_i \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} + \delta_a \begin{pmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 2 \end{pmatrix} + \delta_r \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$



$$\delta_i = \frac{1}{3} \text{Tr}\{\underline{\delta}\} = \frac{1}{3}(\delta_{XX} + \delta_{YY} + \delta_{ZZ})$$

$$\delta_a = \frac{1}{3} \Delta_\delta = \frac{1}{6} (2\delta_{ZZ} - (\delta_{XX} + \delta_{YY}))$$

$$\delta_r = \frac{1}{3} \eta_\delta \Delta_\delta = \frac{1}{2} (\delta_{XX} - \delta_{YY})$$



$$\begin{aligned}
 \vec{B}_e = & \delta_i B_0 \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} + \delta_a B_0 \begin{pmatrix} 3 \sin \vartheta \cos \vartheta \cos \varphi \\ 3 \sin \vartheta \cos \vartheta \sin \varphi \\ 3 \cos^2 \vartheta - 1 \end{pmatrix} \\
 & + \delta_r B_0 \begin{pmatrix} -(2 \cos^2 \chi - 1) \sin \vartheta \cos \vartheta \cos \varphi + 2 \sin \chi \cos \chi \sin \vartheta \sin \varphi \\ -(2 \cos^2 \chi - 1) \sin \vartheta \cos \vartheta \sin \varphi - 2 \sin \chi \cos \chi \sin \vartheta \cos \varphi \\ +(2 \cos^2 \chi - 1) \sin^2 \vartheta \end{pmatrix}
 \end{aligned}$$

