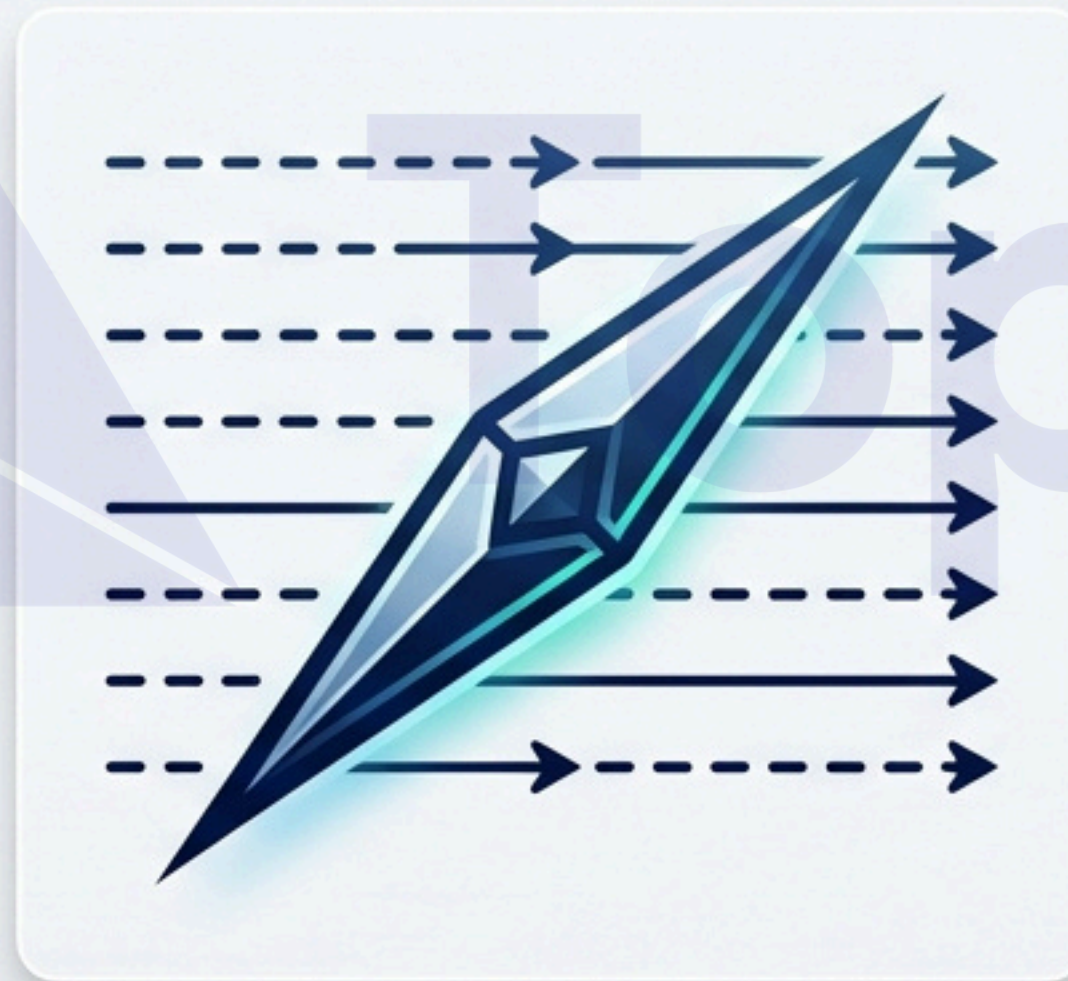
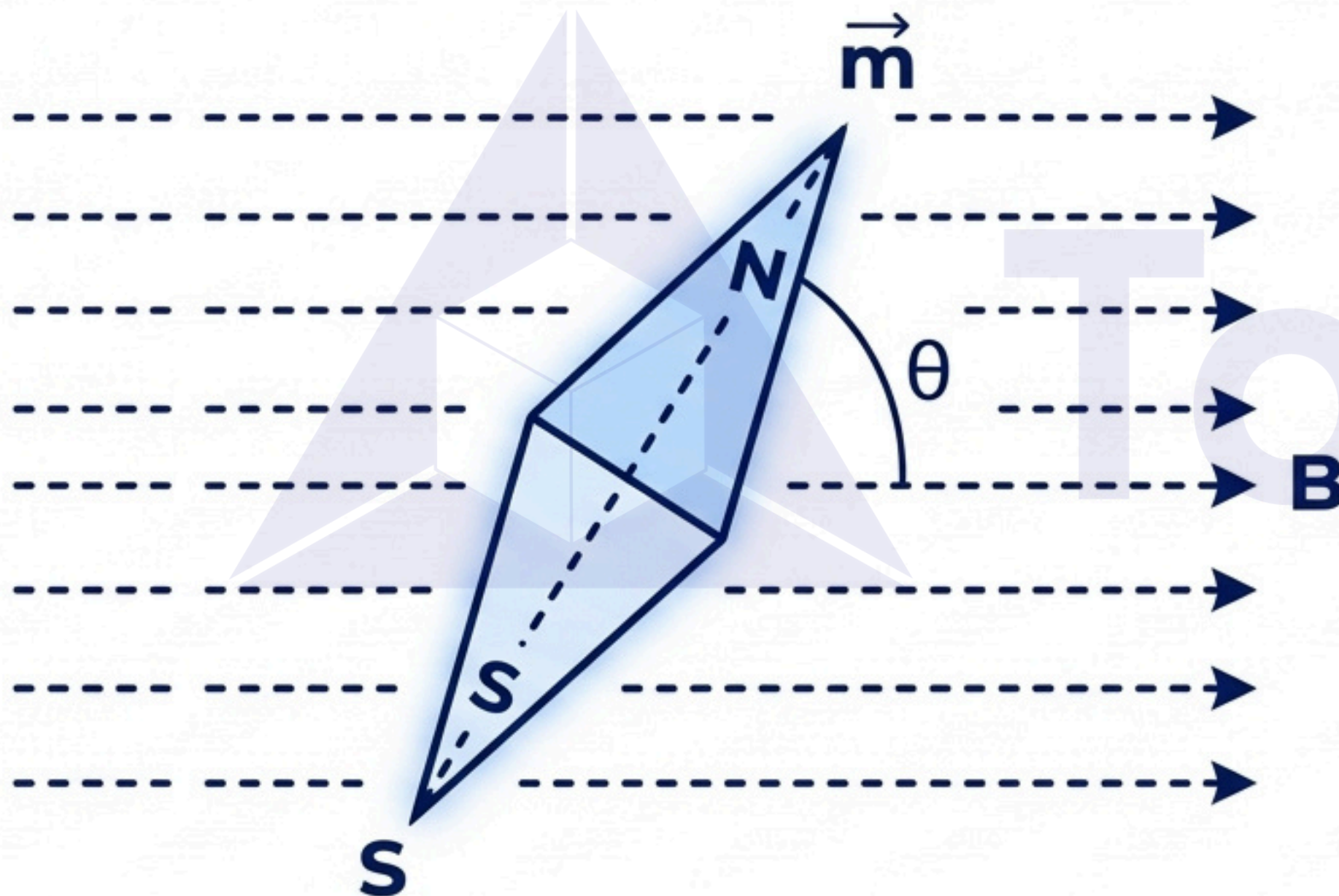


The Dipole in a Uniform Magnetic Field

Dynamics, Potential Energy, and Stability of a Magnetic Needle



The Compass in a Uniform Field



The Field

Uniform magnetic field ($\mathbf{B}$) flows evenly across the space.

The Dipole

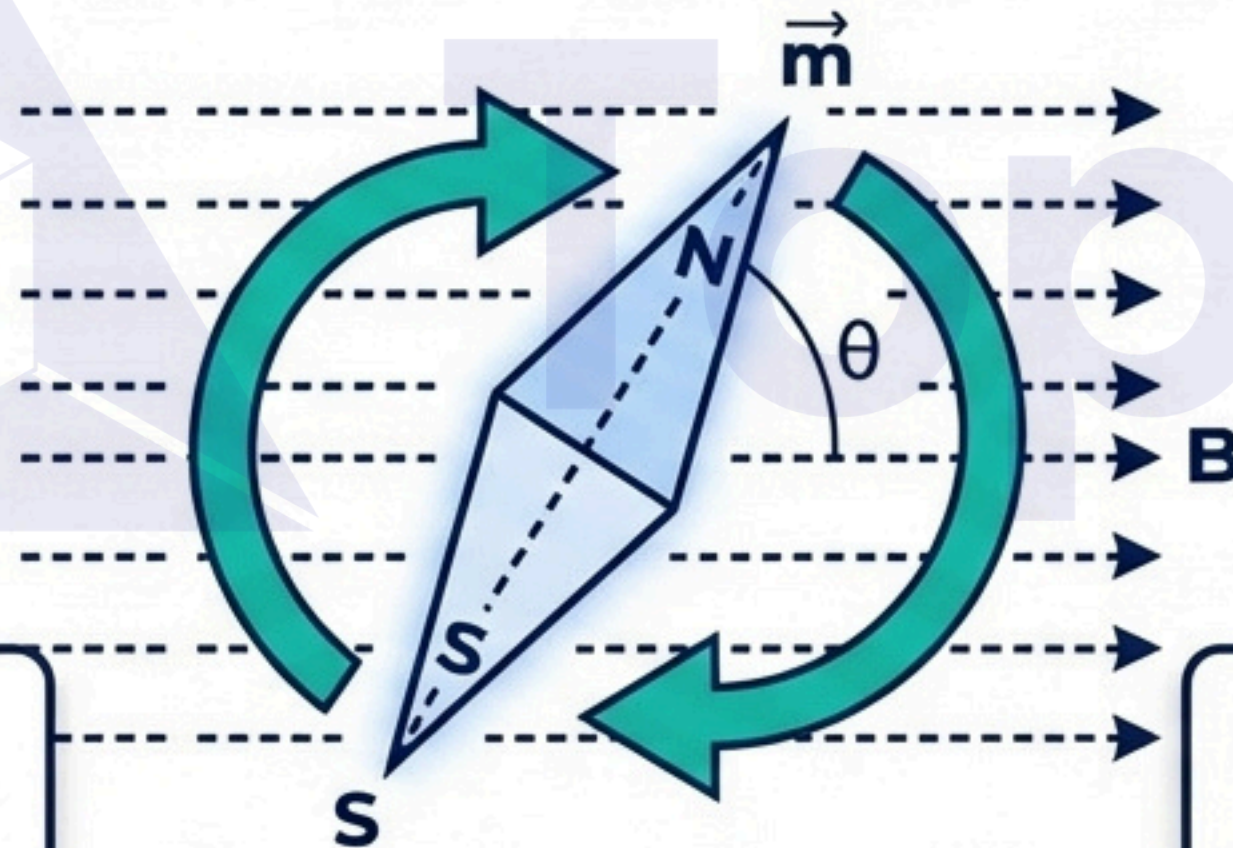
A compass needle acts as a magnetic dipole with magnetic moment ($\mathbf{m}$).

The Angle

θ is the crucial angle between the dipole vector $\mathbf{m}$ and the external field vector $\mathbf{B}$.

The Restoring Torque

$$\tau = \mathbf{m} \times \mathbf{B}$$



Cross Product

Torque is a vector cross product, acting perpendicular to both $\mathbf{m}$ and $\mathbf{B}$.

Restoring Nature

The torque actively tries to align the dipole's magnetic moment with the external field.



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Let's Test Them Now.**

$$E=mc^2$$



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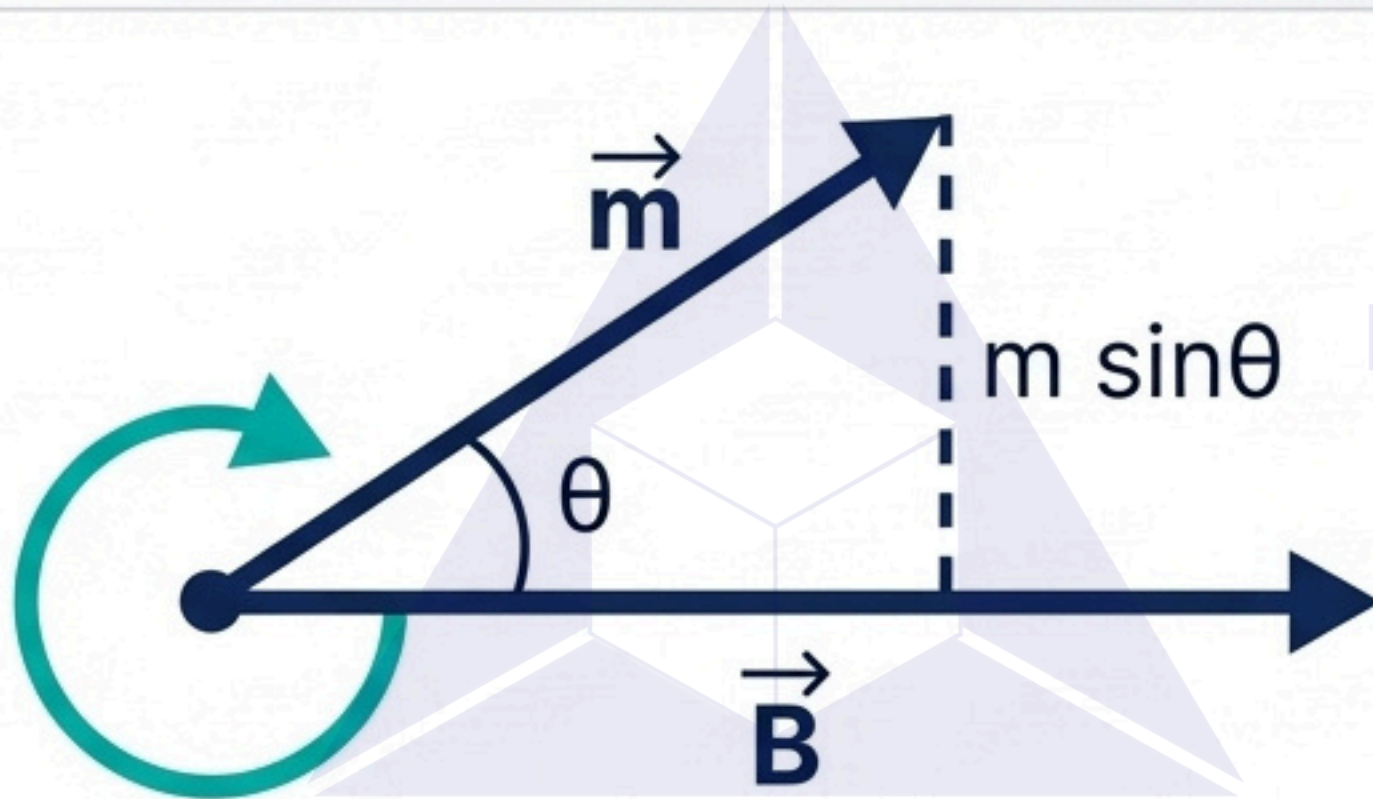
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Calculating the Turning Force



$$|\tau| = mB \sin \theta$$

Max Torque: Occurs at $\theta = 90^\circ$ (when $\sin \theta = 1$).

Zero Torque: Occurs at $\theta = 0^\circ$ or 180° (when perfectly aligned or anti-aligned).

Magnetic Potential Energy

Potential energy (U) is the work done against the restoring torque to rotate the dipole.

$$U = \int \tau d\theta = \int mB \sin\theta d\theta$$

$$\mathbf{U} = -\mathbf{m} \cdot \mathbf{B} = -mB \cos\theta$$

The Zero Point

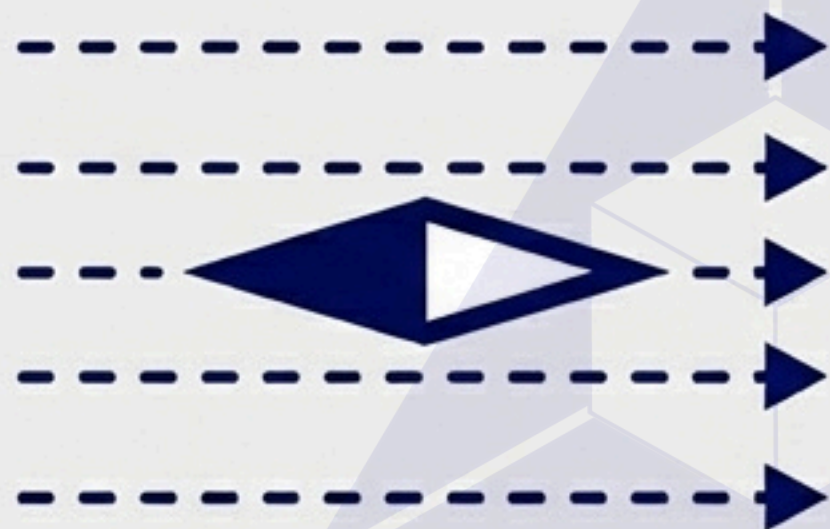
By textbook convention, the constant of integration fixes $U = 0$ at $\theta = 90^\circ$ (perpendicular).

The Extremes

Energy dictates stability. The system naturally seeks the lowest potential energy state.

Analyzing Dipole Stability

Most Stable

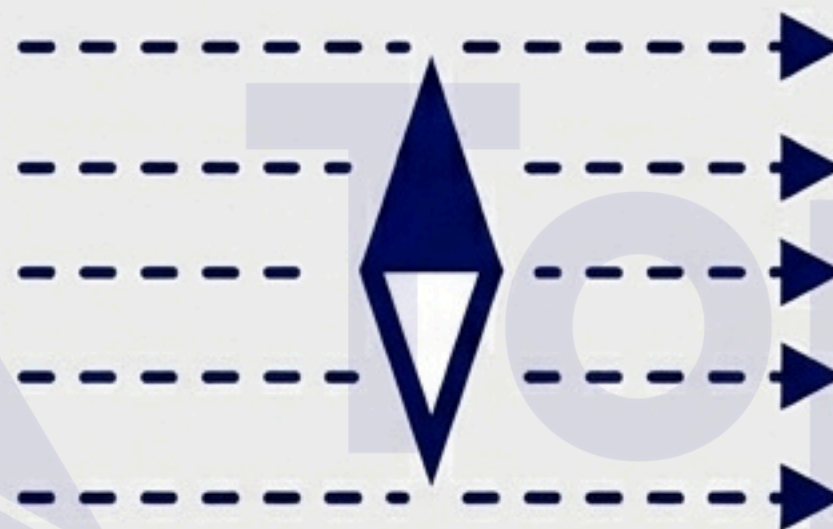


$$\theta = 0^\circ \mid \cos(\theta) = 1$$

$$U = -mB \text{ (Minimum)}$$

Stable Equilibrium

Reference State

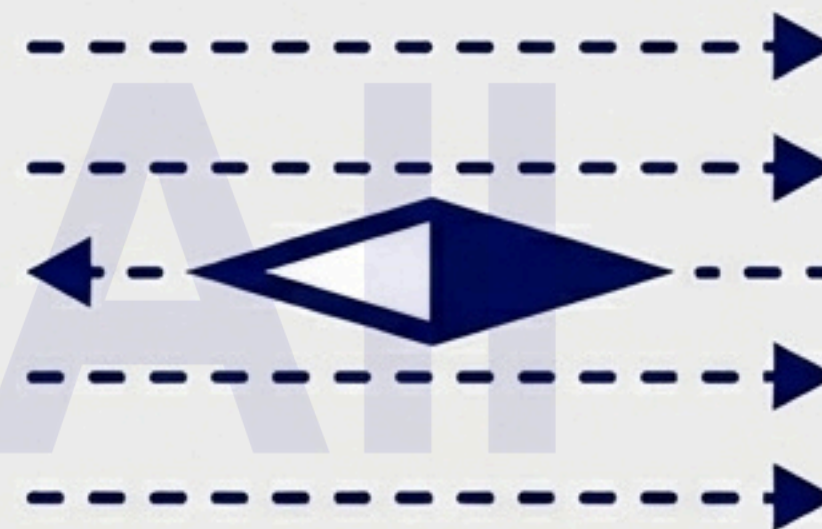


$$\theta = 90^\circ \mid \cos(90) = 0$$

$$U = 0$$

Zero Potential

Most Unstable



$$\theta = 180^\circ \mid \cos(180) = -1$$

$$U = +mB \text{ (Maximum)}$$

Unstable Equilibrium

Exam-Ready Summary

$$\boldsymbol{\tau} = \mathbf{m} \times \mathbf{B}$$

$$|\boldsymbol{\tau}| = mB \sin \theta$$

$$U = -\mathbf{m} \cdot \mathbf{B} = -mB \cos \theta$$

Key Takeaways

- Dipoles experience torque, but no net force in a uniform field.
- Torque acts purely to align the dipole with $\mathbf{B}$.

Exam Trap Alert

Watch out: Zero torque does not always mean stable! At 180° , torque is zero, but it is an unstable equilibrium (maximum potential energy). It will spontaneously flip if nudged.



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