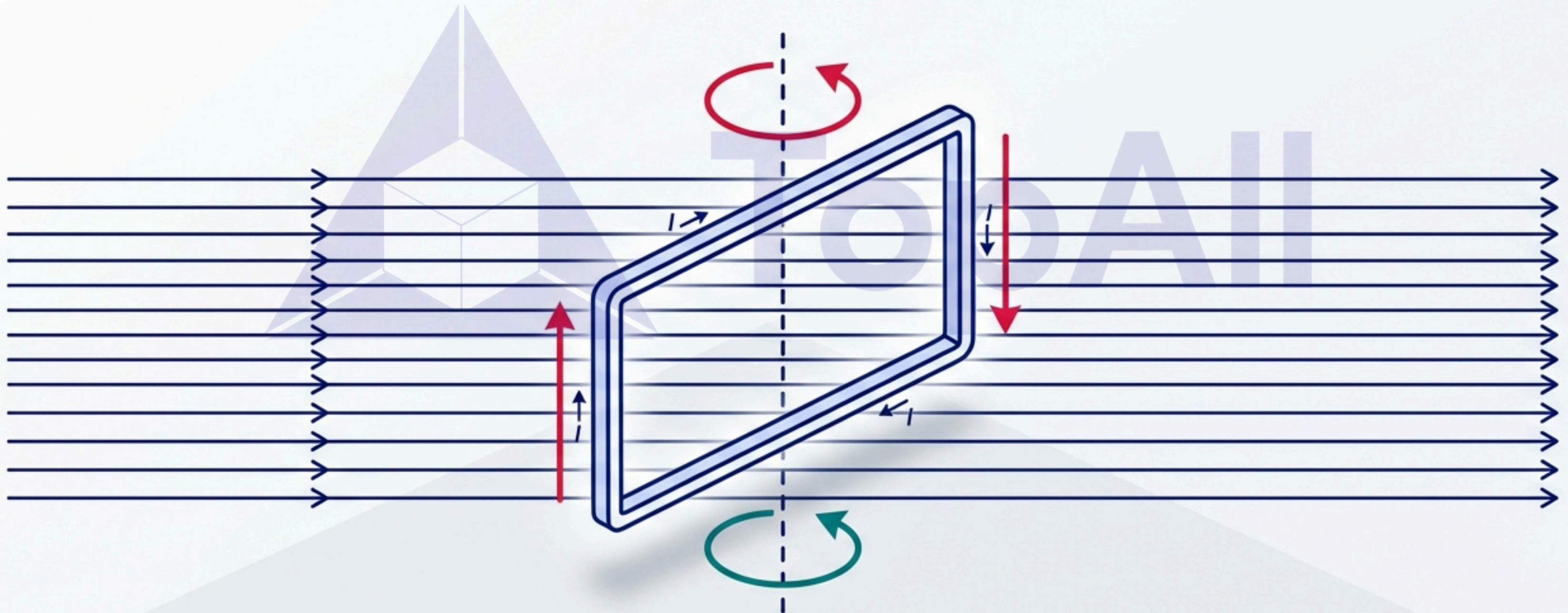


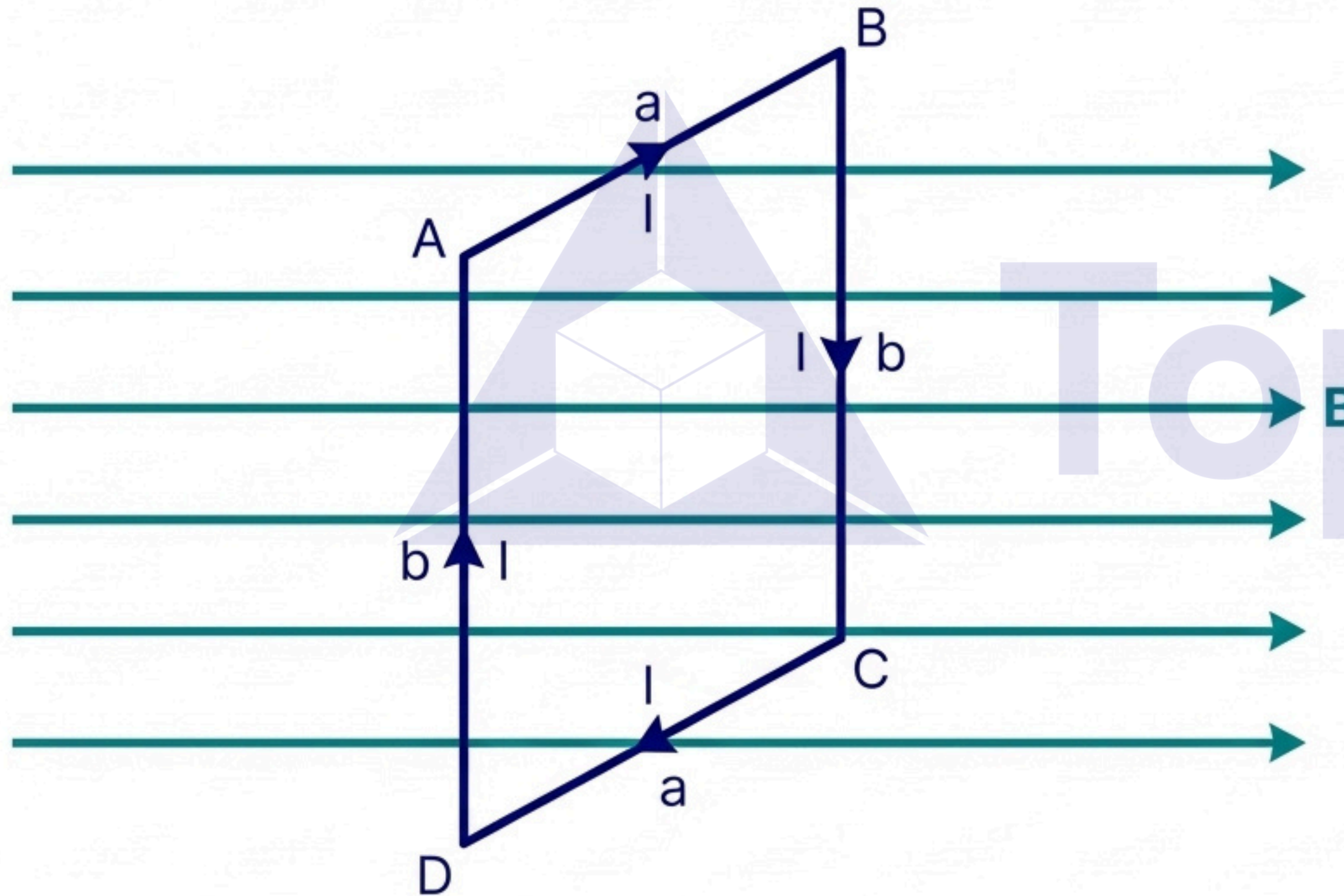
# Torque on a Rectangular Current Loop

Deriving the mechanics of rotational motion in a uniform magnetic field for NEET/JEE.



# Defining the System Geometry

Establishing the physical parameters and spatial orientation of the loop.



## SYSTEM PARAMETERS

$I$  = Steady Current

$a, b$  = Loop Dimensions

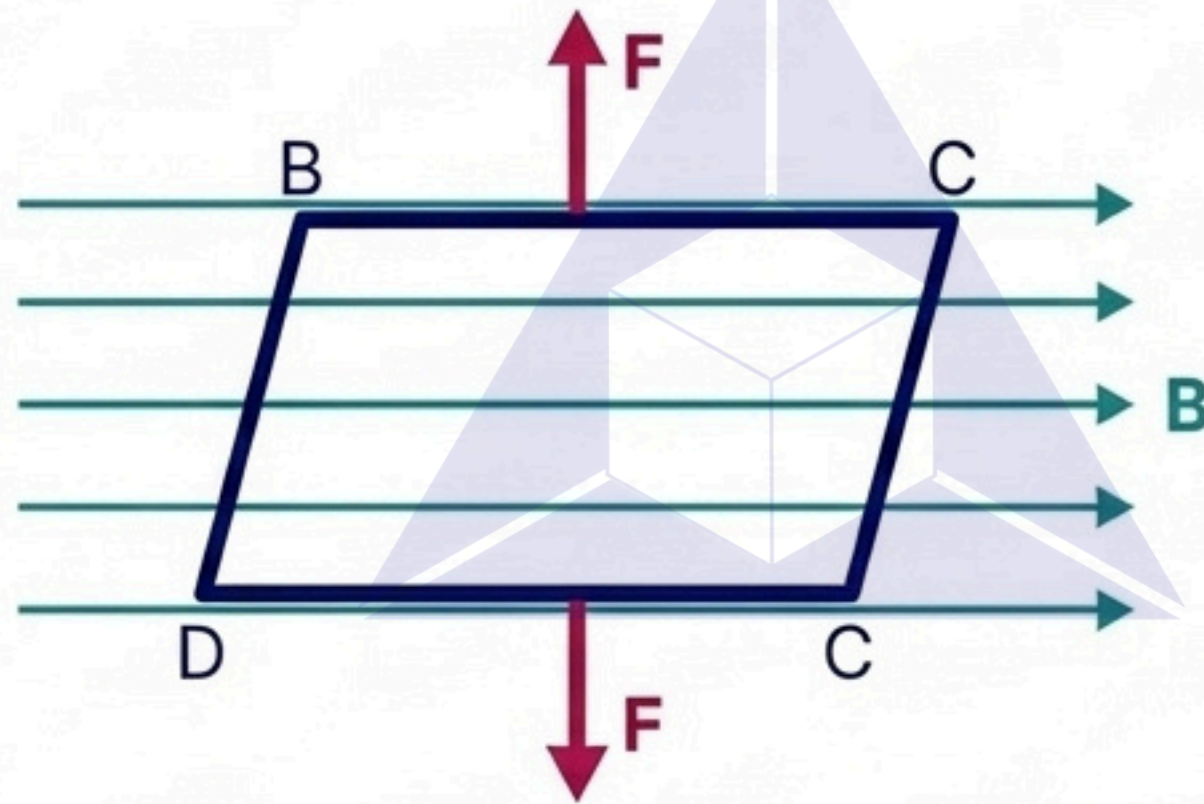
$\mathbf{B}$  = Uniform Magnetic Field

$\mathbf{A} = \mathbf{a} \times \mathbf{b}$  = Area of the Loop

# Component Analysis: Forces on Opposite Sides

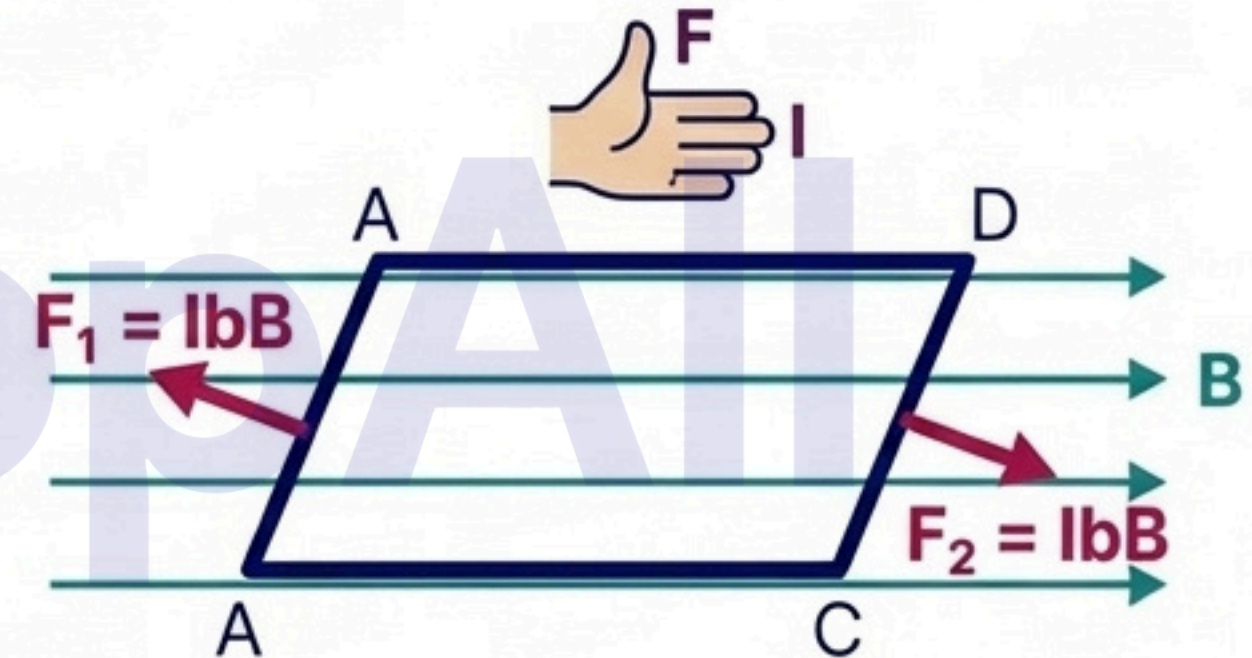
Calculating the Lorentz force ( $\mathbf{F} = \mathbf{I} \times \mathbf{B}$ ) on all four arms when the loop's plane is parallel to the field.

## Arms BC & DA (Inactive)



Forces are equal, opposite, and collinear. Their lines of action intersect. Net effect: They cancel out entirely ( $F = 0$ ,  $\tau = 0$ ).

## Arms AB & CD (Active)



Forces are equal and opposite, but act along different lines.  $F_1 = F_2 = IbB$ . Net translational force is zero, but a rotational effect is created.



**You've Learned the Theory.  
Let's Test Them Now.**

$$E=mc^2$$



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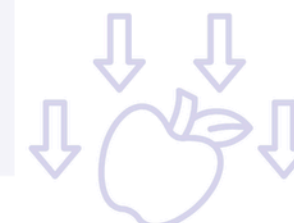
**Practice Now**



At [prep.topall.app](https://prep.topall.app)

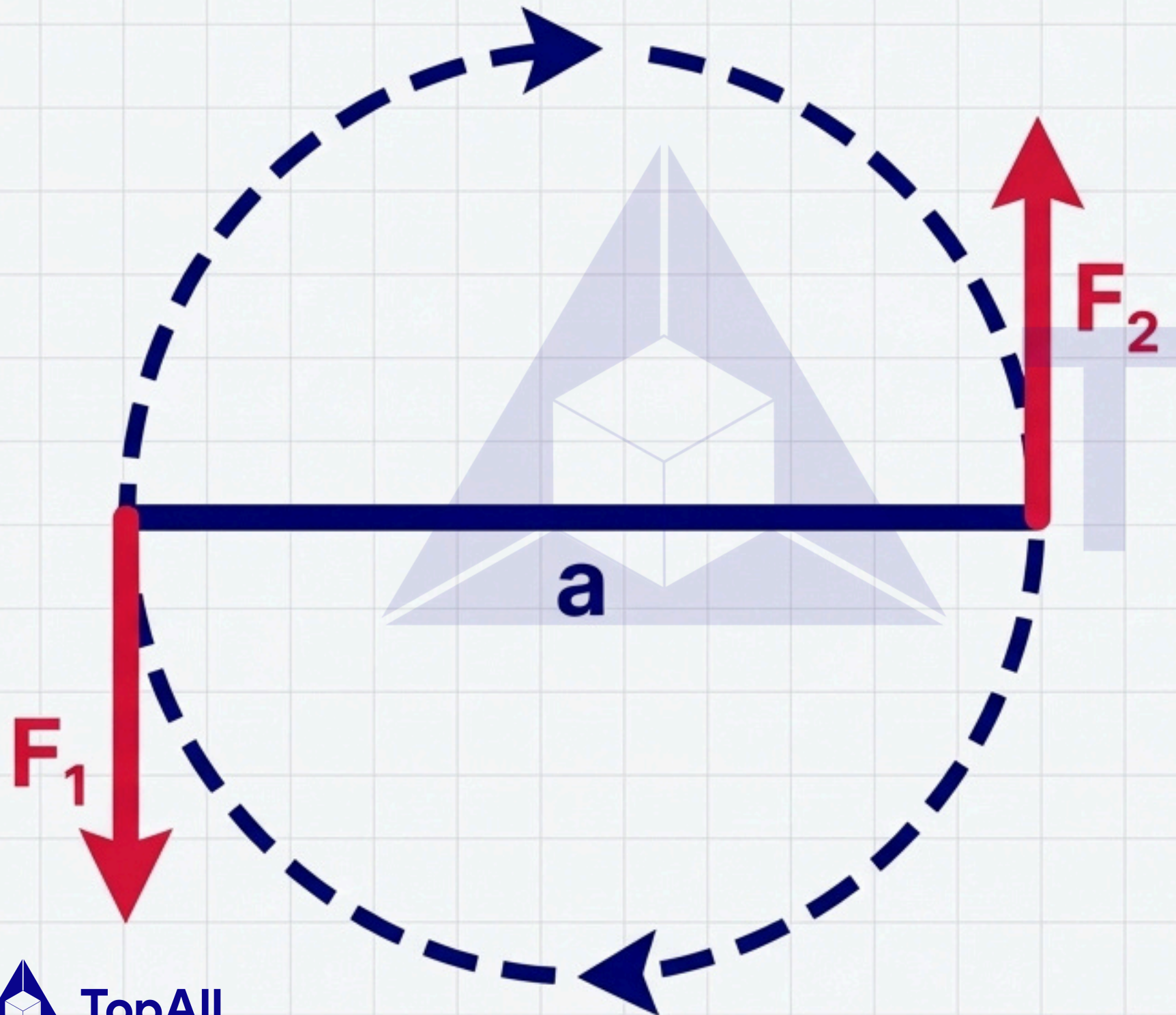
### Key Highlights

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# The Couple Paradox: Net Force = 0, but Torque $\neq 0$

Why **equal** and opposite forces cause rotation when their lines of action are separated.



## The Mechanical Couple

**Observation 1:** Net Force is zero ( $\sum F = 0$ ). There is no translational motion.

**Observation 2:** The lines of action are parallel but separated by perpendicular distance  $a$ .

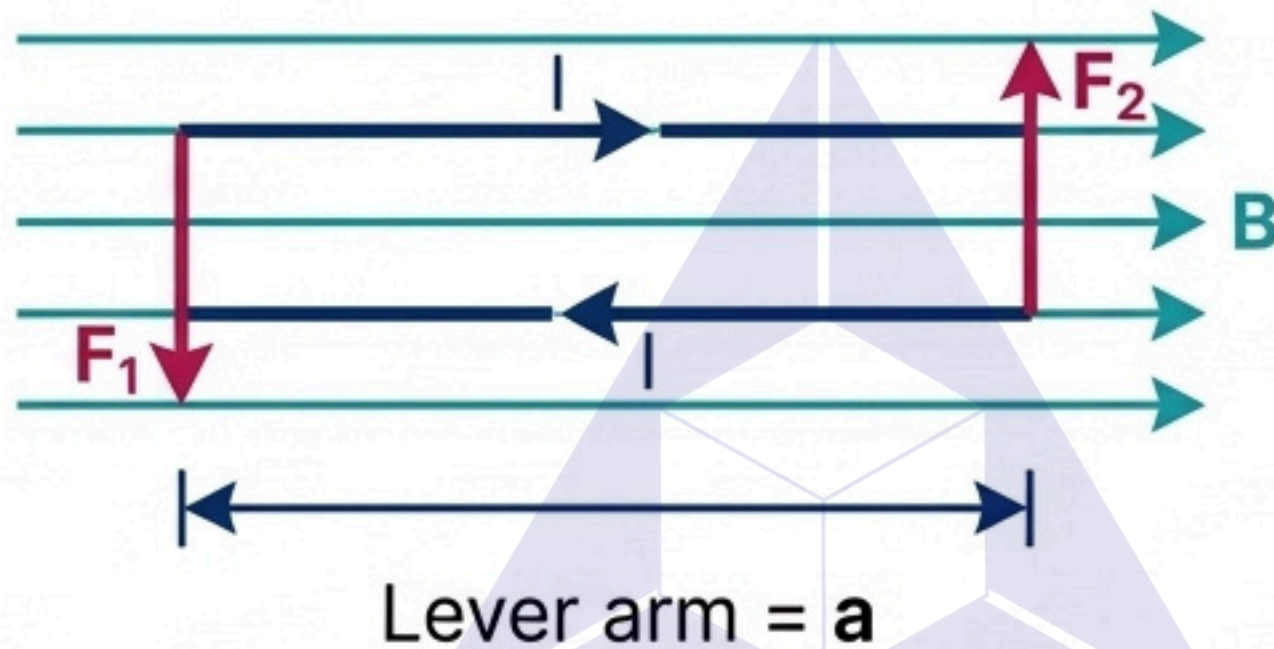
**Conclusion:** This forms a 'Couple', resulting in a twisting force known as Torque.

$$\tau = F_1\left(\frac{a}{2}\right) + F_2\left(\frac{a}{2}\right) = (lbB)a = l(ab)B$$

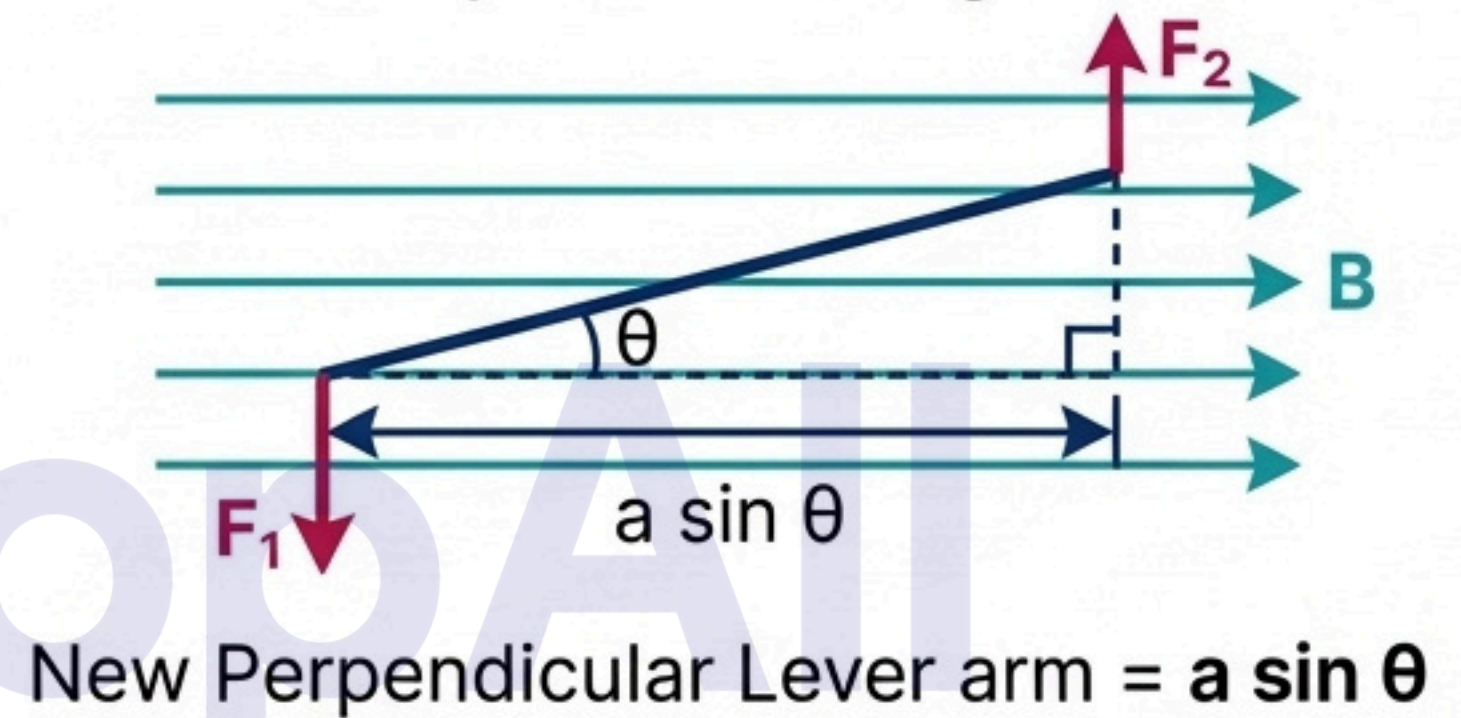
# Generalizing the Torque Formula

Introducing the angle  $\theta$  and Magnetic Moment ( $\mathbf{m}$ ).

Loop Parallel to Field ( $\theta = 0^\circ$ )



Loop Tilted at Angle  $\theta$



1. Perpendicular distance becomes  $a \sin \theta$ .
2.  $\tau = I b \mathbf{B} \times (a \sin \theta) = I(ab) \mathbf{B} \sin \theta = IAB \sin \theta$ .
3. For  $N$  closely wound turns:  $\tau = N I A B \sin \theta$ .

Magnetic Moment:  $\mathbf{m} = N I \mathbf{A}$

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

# Key Takeaways

Essential exam-focused points for rotational mechanics in magnetic fields.

$$|\tau| = NIAB \sin \theta$$

## Critical Exam Conditions

- **Maximum Torque:** Occurs when  $\theta = 90^\circ$  (plane of the loop is parallel to the magnetic field  $\mathbf{B}$ ).
- **Stable Equilibrium:** Occurs when  $\mathbf{m}$  is parallel to  $\mathbf{B}$  ( $\tau = 0$ ,  $\theta = 0^\circ$ ). The loop resists displacement.
- **Unstable Equilibrium:** Occurs when  $\mathbf{m}$  is anti-parallel to  $\mathbf{B}$  ( $\tau = 0$ ,  $\theta = 180^\circ$ ).

**Concept Link:** This exact principle is the foundational mechanism behind the Moving Coil Galvanometer and standard electric motors.



# You've Learned the Theory.

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