

Torque & Rotational Dynamics

AP Physics 1 ■ Unit 5

AP Physics 1



Torque & Rotational Dynamics

What we will cover

- 1 Rotational kinematics
- 2 Linking linear and rotational motion
- 3 Torque
- 4 Rotational inertia
- 5 Rotational equilibrium
- 6 Newton's second law for rotation



1 Rotational kinematics

Torque & Rotational Dynamics

Rotational kinematics

Rotation mirrors straight-line motion

Spinning is described by angles:

- **angular velocity** 角速度 ω – rate the angle turns
- **angular acceleration** 角加速度 α – rate ω changes

For constant α , the equations have the **same form** as the linear ones. Rotation rate: $\omega = 2\pi f$.



Rotation links angle, angular speed, and linear speed

Torque & Rotational Dynamics

Rotational kinematics

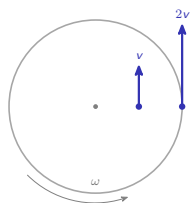
Linking linear and rotational motion

Every point on a spinning body moves along a curve, tied to the **radius** 半径 r :

Same ω , different v

$$v = r\omega, \quad a_t = r\alpha, \quad s = r\theta$$

All points share one ω , but points farther out move **faster**.



2 Torque

Torque

Torque 力矩 is the rotational version of force – how strongly a force twists:

Twisting strength

$$\tau = rF \sin \theta$$

The **lever arm** 力臂 is the perpendicular distance to the force. A bigger lever arm gives **more torque**.



Torque is the rotational analogue of force

3 Rotational inertia

Rotational inertia

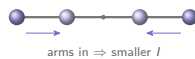
Rotational inertia 转动惯量 I resists a change in spin – and depends on **how the mass is spread**:

Distance is squared

$$I = \sum mr^2$$

Parallel-axis theorem 平行轴定理: $I = I_{cm} + md^2$.

Move mass out to $2\times$ the radius $\Rightarrow I$ grows $4\times$.



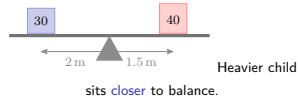
arms in $\Rightarrow$ smaller I

4 Equilibrium

Rotational equilibrium

In **rotational equilibrium** 转动平衡 the **net torque** 净力矩 is zero. Full **static equilibrium** 静平衡: both net force **and** net torque zero.

- pick the axis at an unknown force to drop it out
- set clockwise torque = counterclockwise torque



5 Rotational Newton's law

Newton's second law for rotation

A nonzero net torque gives an angular acceleration – just like $F = ma$:

Rotational form

$$\tau_{\text{net}} = I\alpha$$

torque $\leftrightarrow$ force, $I \leftrightarrow$ mass, $\alpha \leftrightarrow$ acceleration.

Worked example

$\tau = 12 \text{ N m}$ on $I = 3 \text{ kg m}^2$:

$$\alpha = \frac{\tau}{I} = \frac{12}{3} = 4 \text{ rad/s}^2$$

Double $I \Rightarrow$ half the α – harder to spin up.

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Recap

Unit 5 – key takeaways

1 Analogy

$x, v, a, m, F \leftrightarrow \theta, \omega, \alpha, I, \tau; v = r\omega$

2 Torque

$\tau = rF\sin\theta$; the lever arm sets the twist

3 Inertia

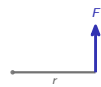
$I = \sum mr^2$; mass farther out counts far more

4 Dynamics

equilibrium: net $\tau = 0$; otherwise $\tau = I\alpha$

Check yourself

- 1 Push a door near the hinge vs at the handle – which gives more torque?
- 2 Move a mass to twice the radius – what happens to I ?
- 3 On a balanced seesaw, who sits closer to the pivot?
- 4 $\tau = 20 \text{ N m}$ on $I = 5 \text{ kg m}^2$ – find α .



Answers 1. the handle (bigger lever arm) 2. it quadruples 3. the heavier one
4. 4 rad/s^2