Torque & Rotational Dynamics

AP Physics 1 ▪ Unit 5

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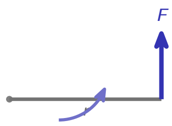
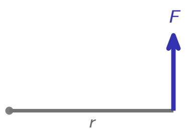


What we will cover



1 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

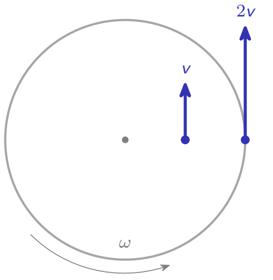
Linking linear and rotational motion

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: $I = I_{cm} + md^2$.

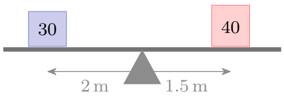
Move mass out to $2\times$ the radius $\Rightarrow$ I grows $4\times$.

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



Heavier child sits closer to balance.

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

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

torque ↔ force, I ↔ mass, α ↔ acceleration.

Worked example

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

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

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

6 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**

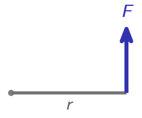
$I = \sum mr^2$; mass farther out counts far more

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. $\tau = 20\,\mathrm{N\,m}$ on $I = 5\,\mathrm{kg\,m^2}$ – find α.



Answers **1.** the handle (bigger lever arm) **2.** it quadruples **3.** the heavier one **4.** $4\,\mathrm{rad/s^2}$