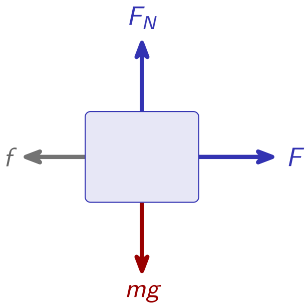
Force & Translational Dynamics

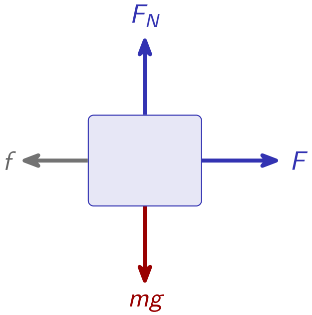
AP Physics 1 ▪ Unit 2

AP Physics 1



What we will cover

1. Systems and center of mass
2. Free-body diagrams
3. Newton's three laws
4. Gravity and weight
5. Friction
6. Spring forces
7. Circular motion



1 Systems & center of mass

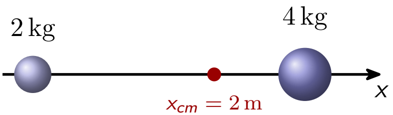
Systems and center of mass

Treat several objects as one **system** 系统. Its **center of mass** 质心 moves as if all mass sat there.

Center of mass

$$x_{cm} = \frac{m_1 x_1 + m_2 x_2 + \dots}{m_1 + m_2 + \dots}$$

> Only the **net external force** 净外力 moves the center of mass – **internal forces** 内力 cannot.



Closer to the heavier mass.

2 Free-body diagrams

Free-body diagrams

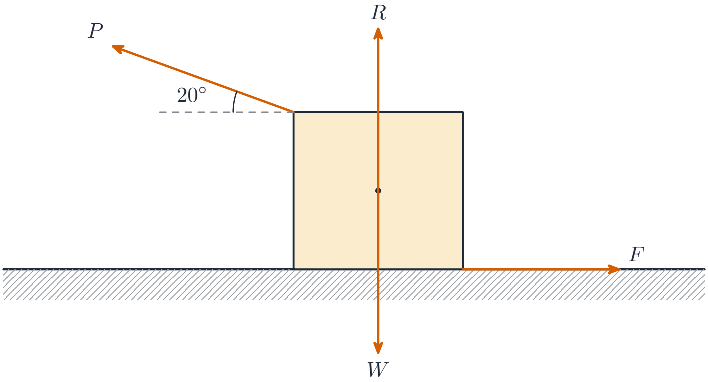
A **force** 力 is a push or pull, in newtons. Draw a **free-body diagram** 受力图: the object as a dot, every force as a labeled arrow.

- **contact forces** 接触力 – normal, friction
- **long-range forces** 长程力 – gravity

> Add the arrows as vectors to get the **net force** 合力.

Free-body diagrams show every force on a system

Forces and Free-Body Diagrams



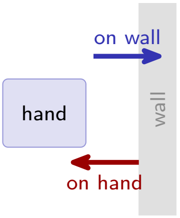
A free-body diagram shows every force acting on one object

3 Newton's laws

Newton's third law

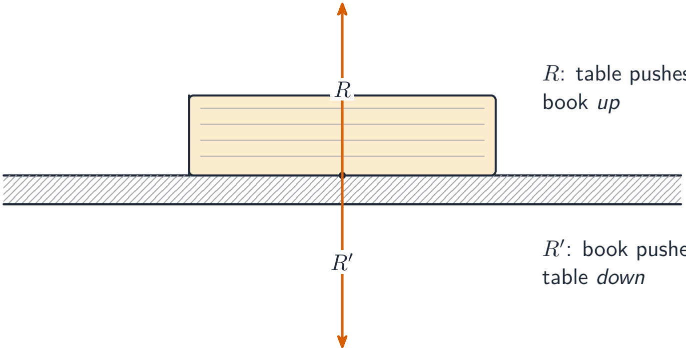
Newton's third law 牛顿第三定律: if A pushes B, then B pushes A back – equal in size, opposite in direction.

> The two forces of a **force pair** 作用力对 act on different objects, so they can *never* cancel.



$50\,\mathrm{N}$ each, on different bodies.

A Newton's third-law pair



R: table pushes the book *up*

R': book pushes the table *down*

> A Newton's third-law pair: equal and opposite forces on two different objects

Newton's first law

Newton's first law 牛顿第一定律: velocity stays constant unless a net force acts.

- **inertia** 惯性 – resistance to a change in motion, measured by mass
- net force zero = **translational equilibrium** 平动平衡

> "No net force" means no change in motion – not "no motion".

Rockets accelerate by pushing exhaust out

Newton's second law

Newton's second law 牛顿第二定律: a nonzero net force gives an acceleration.

The rule

$$\vec{a} = \frac{\sum \vec{F}}{m}$$

On a ramp, resolve forces into **perpendicular components** 垂直分量 and apply it in each direction.

Worked example

$20\,\mathrm{N}$ on a $5\,\mathrm{kg}$ box:

$$a = \frac{20}{5} = 4\,\mathrm{m/s^2}$$

Double the mass $\Rightarrow$ the acceleration halves.

$a \propto F$, and $a \propto 1/m$.

4 Gravity

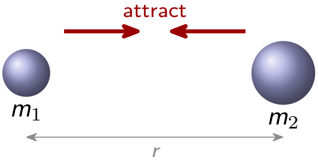
Gravitational force

Universal gravitation

$$F_g = \frac{G m_1 m_2}{r^2}$$

Grows with mass; falls with the square of the distance.

Mass 质量 is fixed matter;
weight 重量 $= mg$ changes with location.



$10\,\mathrm{kg}$ rock:

$98\,\mathrm{N}$ on Earth, $16\,\mathrm{N}$ on the Moon.

5 Friction

Friction

Friction opposes sliding, and depends on the **normal force** 法向力 F_N and **coefficient of friction** 摩擦系数 μ – not the area.

Two forms

$$\text{static: } f_s \leq \mu_s F_N$$

$$\text{kinetic: } f_k = \mu_k F_N$$

Worked example ($10\,\mathrm{kg}$, $\mu_s = 0.4$)

$$F_N = mg = 98\,\mathrm{N}$$

$$f_{s,\max} = 0.4 \times 98 = 39\,\mathrm{N}$$

Push $< 39\,\mathrm{N}$: it stays. Push harder: it breaks free, then weaker **kinetic friction** 动摩擦 takes over.

Worked example – will the crate move?

A 5.0 kg crate on a level floor has $\mu_s = 0.40$. Will a horizontal push of 15 N move it?

- on a level floor
  $N = mg = (5.0)(9.8) = 49$ N
- maximum static friction:
  $f_{s,\max} = \mu_s N = 0.40(49) = 19.6$ N
- 15 N < 19.6 N, so no – it stays at rest
- static friction takes the value 15 N, exactly balancing the push

Static friction is an inequality: it supplies whatever is needed, up to its maximum. Setting $f_s = \mu_s N$ before checking is the standard error.

6

Springs

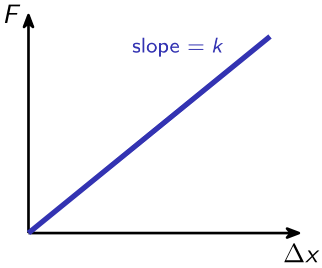
Spring forces – Hooke's law

Hooke's law

$$F_s = -k\,\Delta x$$

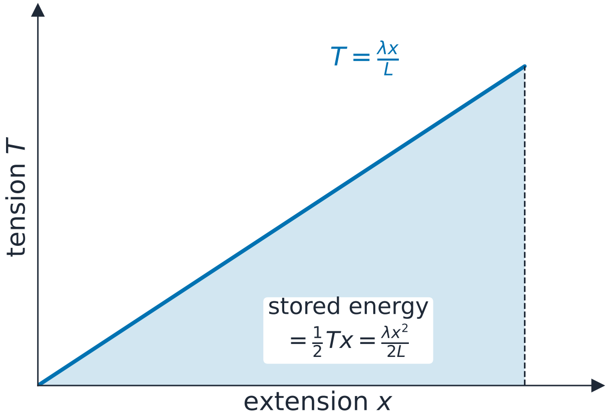
spring constant 弹簧劲度系数 k = stiffness. The minus sign makes it a **restoring force** 回复力.

> k is the slope of the force–displacement graph.



10 N over 0.20 m: $k = 50\,\mathrm{N/m}$.

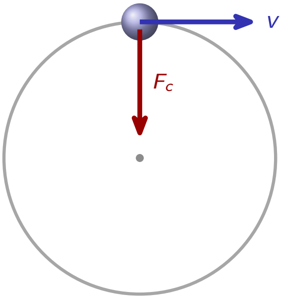
Hooke's law



> Hooke's law: extension is proportional to load up to the limit of proportionality

7 Circular motion

Uniform circular motion



Uniform circular motion 匀速圆周运动: steady speed, changing direction – so it accelerates.

Toward the center

$$a_c = \frac{v^2}{r}, \qquad F_c = \frac{mv^2}{r}$$

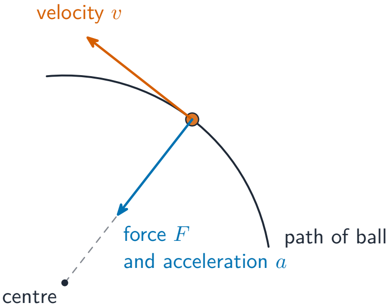
Centripetal force 向心力 is a role – filled by tension, gravity, or friction. Cut it, and the object flies off straight.

Uniform circular motion, in its own words

Period and frequency	The **period** T is the time for one revolution; the **frequency** $f = 1/T$ is revolutions per second.
Speed	$v = \dfrac{2\pi r}{T}$ – one circumference in one period.
Centripetal acceleration	**Centripetal acceleration** $a_c = \dfrac{v^2}{r}$, directed towards the centre. The speed is constant; the velocity is not.
The force	$F_{net} = ma_c$, supplied by whatever actually points inward – tension, friction, gravity, the normal force.

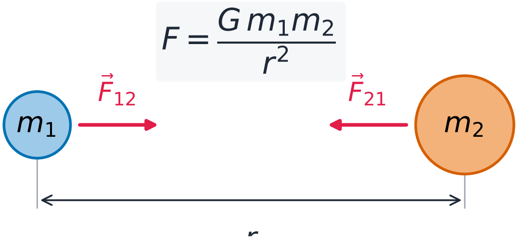
> "Centripetal force" is a *role*, never a new force. Name the real force filling it, or the free-body diagram is wrong.

Circular Motion



The velocity points along the tangent; the centripetal force and acceleration point to the centre

Gravitational Force, continued



$|\vec{F}_{12}| = |\vec{F}_{21}|$ (action–reaction; inverse-square)

> Two masses attract each other with equal, opposite, inverse-square forces along the line joining them

Mass plays two distinct roles

inertial mass 惯性质量	how strongly an object resists acceleration – the m in $F = ma$
gravitational mass 引力质量	how strongly it attracts and is attracted – the m in the law of gravitation
the remarkable fact	experiment finds them equal, to extraordinary precision
the consequence	all objects fall with the same acceleration, because the extra weight is exactly cancelled by the extra inertia
Newton's law of gravitation 万有引力定律	$F = \dfrac{Gm_1 m_2}{r^2}$
gravitational field strength 引力场强度	$g = \dfrac{GM}{r^2}$ – force per unit mass, and numerically the free-fall acceleration

> That the two masses are equal is why Galileo's result holds. It is an experimental fact, not a definition – and Einstein made it the starting point of general relativity.

Exam tips

- Always draw a **free-body diagram** first: only real forces **on** the chosen object (weight, normal, tension, friction, applied) – never an "*ma*" arrow.
- Apply $\sum F = ma$ **one axis at a time**; on an incline resolve gravity into $mg \sin\theta$ (along) and $mg \cos\theta$ (perpendicular).
- A **Newton's third-law pair** acts on **two different objects** – a book's weight and the table's normal force are *not* a pair (both act on the book).
- **Static friction** adjusts up to $\mu_s N$ (use it to test whether motion starts); once sliding, use **kinetic** friction $f_k = \mu_k N$.
- Circular motion needs a **net inward (centripetal) force** mv^2/r supplied by a real force – there is no outward "centrifugal" force.

8 Recap

Unit 2 – key takeaways

1 **Free-body**

draw every force as an arrow; add them for the net force

2 **Newton's laws**

1st: inertia; 2nd: $a = \Sigma F/m$; 3rd: equal-opposite pairs

3 **Forces**

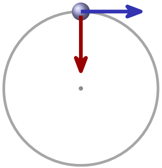
gravity $Gm_1 m_2/r^2$; friction μF_N; spring $-k\Delta x$

4 **Circular**

$a_c = v^2/r$ toward the center; a role, not a new force

Check yourself

1. Why can a Newton's-third-law pair never cancel?
2. $30\,\mathrm{N}$ net on a $6\,\mathrm{kg}$ mass – what is a?
3. Does friction depend on the contact area?
4. Cut the string on a whirling ball – which way does it go?



Answers **1.** they act on different objects **2.** $5\,\mathrm{m/s^2}$ **3.** no **4.** straight, along the tangent