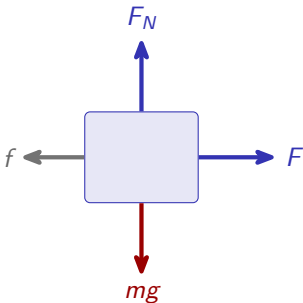


Force & Translational Dynamics

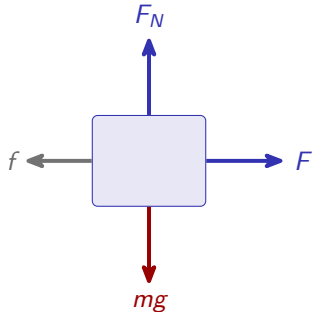
AP Physics 1 ■ Unit 2

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





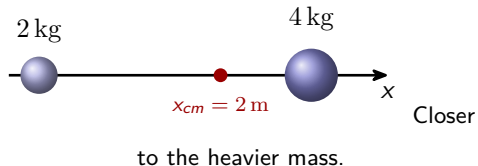
Systems and center of mass

Treat several objects as one **system** . Its **center of mass** 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** moves the center of mass – **internal forces** cannot.





Free-body diagrams

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

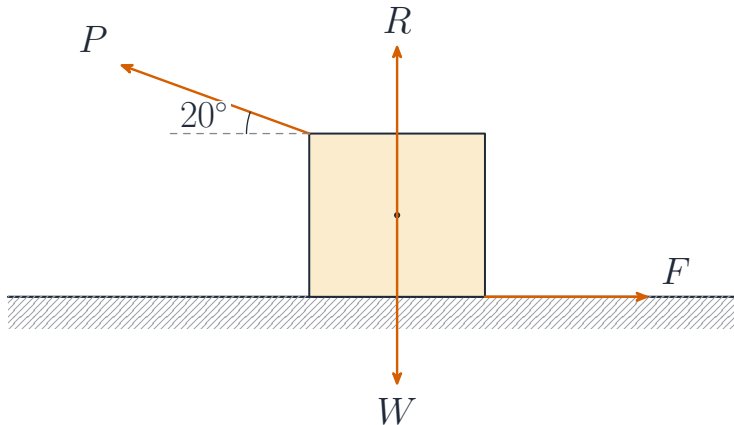
- **contact forces** – normal, friction
- **long-range forces** – gravity

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



Free-body diagrams show every force on a system

Forces and Free-Body Diagrams



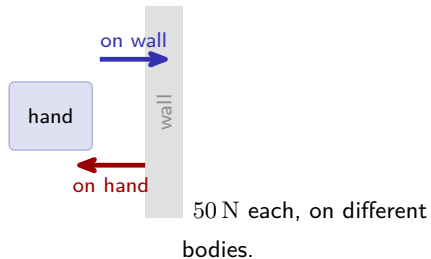
A free-body diagram shows every force acting on one object



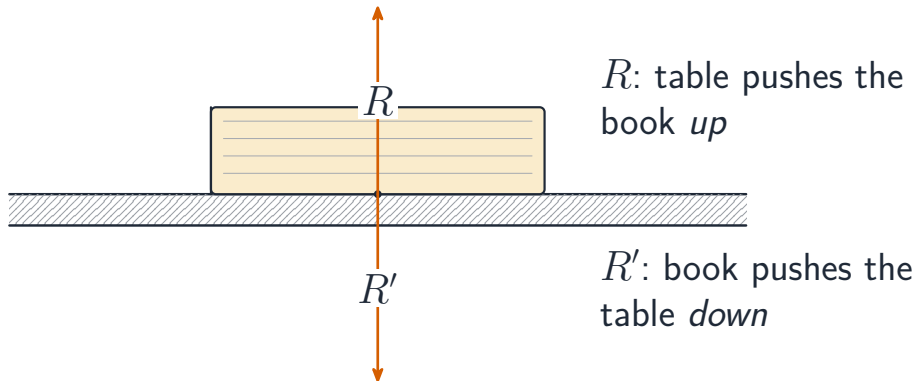
Newton's third law

Newton's third law : if A pushes B, then B pushes A back – **equal in size, opposite in direction**.

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



A Newton's third-law pair



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

Newton's first law

Newton's first law : velocity stays constant unless a net force acts.

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

“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 : a nonzero net force gives an acceleration.

The rule

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

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

Worked example

20 N on a 5 kg box:

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

Double the mass $\Rightarrow$ the acceleration **halves**.

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



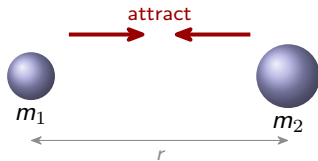
Gravitational force

Universal gravitation

$$F_g = \frac{Gm_1m_2}{r^2}$$

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

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



10 kg rock:

98 N on Earth, 16 N on the Moon.



Friction

Friction opposes sliding, and depends on the **normal force** F_N and **coefficient of friction** 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 kg, $\mu_s = 0.4$)

$$F_N = mg = 98 \text{ N}$$

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

Push $< 39 \text{ N}$: it stays. Push harder: it breaks free, then weaker **kinetic friction** 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
 $N = mg = (5.0)(9.8) = 49 \text{ N}$
- maximum static friction:
 $f_{s,\text{max}} = \mu_s N = 0.40(49) = 19.6 \text{ N}$
- $15 \text{ N} < 19.6 \text{ N}$, 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.



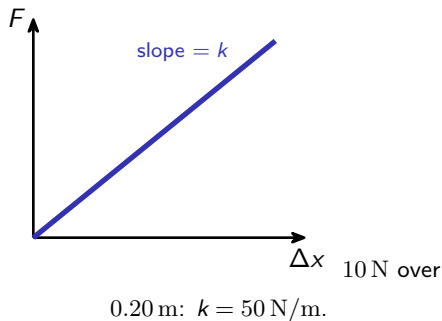
Spring forces – Hooke's law

Hooke's law

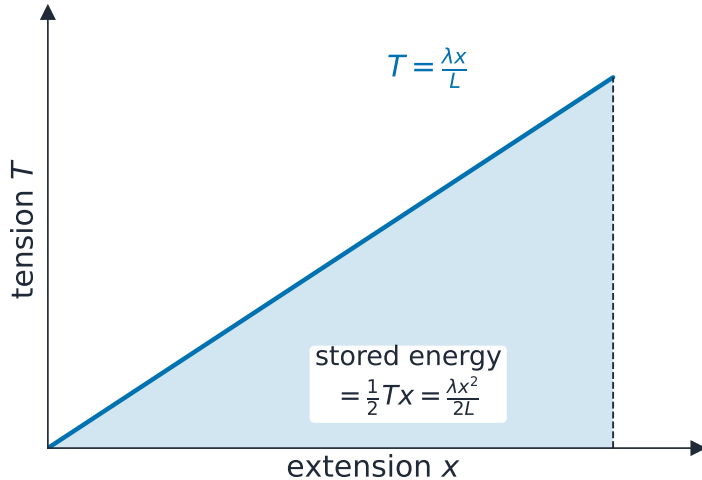
$$F_s = -k \Delta x$$

spring constant k = stiffness. The minus sign makes it a **restoring force**.

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



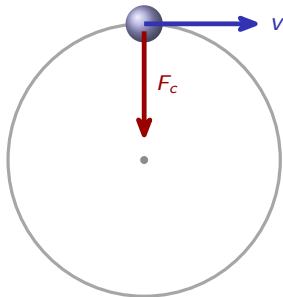
Hooke's law



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



Uniform circular motion



Uniform circular motion : steady speed, changing direction – so it accelerates.

Toward the center

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

Centripetal force 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

$v = \frac{2\pi r}{T}$ – one circumference in one period.

Centripetal acceleration

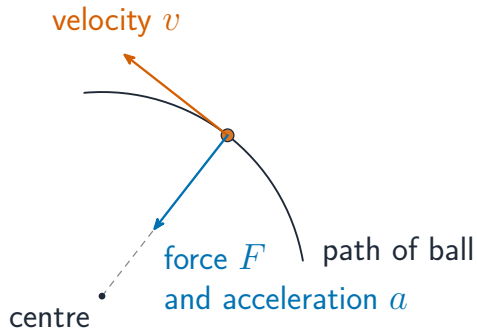
Centripetal acceleration $a_c = \frac{v^2}{r}$, directed towards the centre.
The speed is constant; the velocity is not.

The force

$F_{net} = ma_c$, supplied by whatever actually points inward – tension, friction, gravity, the normal force.

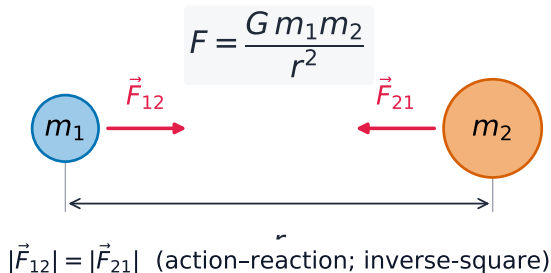
“Centripetal force” is a *role*, never a new force. Name the real force filling it, or the free-body diagram is wrong.

Circular Motion



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

Gravitational Force, continued



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

Mass plays two distinct roles

inertial mass

how strongly an object **resists acceleration** – the m in $F = ma$

gravitational mass

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

$$F = \frac{Gm_1 m_2}{r^2}$$

gravitational field strength

$g = \frac{GM}{r^2}$ – 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.



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_1m_2/r^2 ; friction μF_N ;
spring $-k\Delta x$

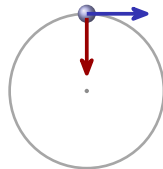
4

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 N net on a 6 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 m/s^2 3. no 4. straight, along the tangent