

Free-body diagrams and net force problems

AP Physics 1 (algebra-based) · Lesson

Quick answer: Newton's laws link force and motion. The first law says zero net force means constant velocity, the second says $\Sigma F = ma$, and the third says forces come in equal and opposite pairs acting on different objects. A free-body diagram shows only the external forces on the chosen system.

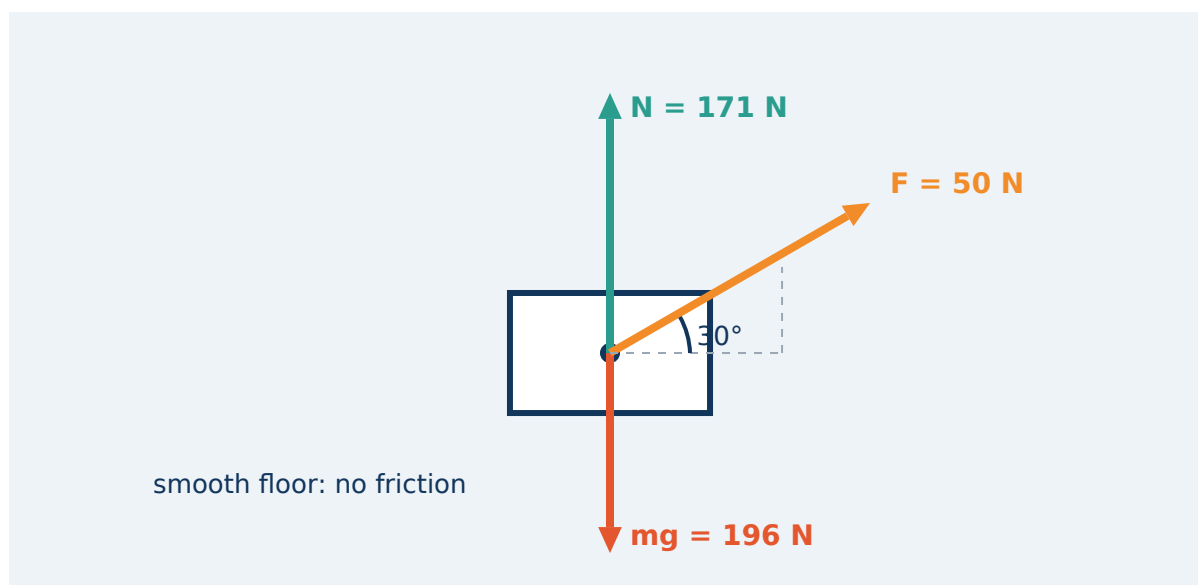
Level: AP Physics 1 (algebra-based) · **Curriculum:** AP P1 Unit 2

What is a force, and how do you draw a free-body diagram?

A force is a push or pull that one object exerts on another. Because forces are vectors, what matters for the motion of a chosen object is their vector sum. In AP Physics 1 unit 2 you first choose the *system*, then draw only the forces that outside objects exert on it.

Definition

A **system** is the object or group of objects chosen for analysis. The **net force** ΣF is the vector sum of all external forces on the system. A **free-body diagram** shows the system as a dot or box with one arrow for each external force.



Dot at the centre of the block; each arrow is a force acting on the block.

Typical forces are weight (the gravitational force of Earth, mg), the normal force N (perpendicular to a surface), tension T (along a rope), friction and applied pushes or pulls. Each arrow is named as the force of one object on another.

What do Newton's first and second laws say?

Key law

First law: if the net force on a system is zero, its velocity does not change (it stays at rest or moves in a straight line at constant speed). **Second law:** the acceleration of a system has the direction of the net force and is proportional to it, inversely proportional to the mass.

Formula

$$\Sigma \mathbf{F} = m\mathbf{a} \quad \mathbf{W} = m\mathbf{g}$$

$\Sigma \mathbf{F}$ = net force (N, where $1 \text{ N} = 1 \text{ kg} \cdot \text{m/s}^2$); m = mass (kg); a = acceleration (m/s^2); W = weight (N); $g = 9.81 \text{ N/kg}$ near Earth's surface.

Apply the second law separately along each axis: $\Sigma F_x = ma_x$ and $\Sigma F_y = ma_y$. If the block does not leave the surface, $a_y = 0$.

Worked example

Bilal pulls a 20 kg block with a 50 N rope at 30° above the horizontal along a smooth floor.

Horizontal: $F \cos 30^\circ = 50 \times 0.866 = 43.3 \text{ N}$, so $a = 43.3 \div 20 = \mathbf{2.2 \text{ m/s}^2}$.

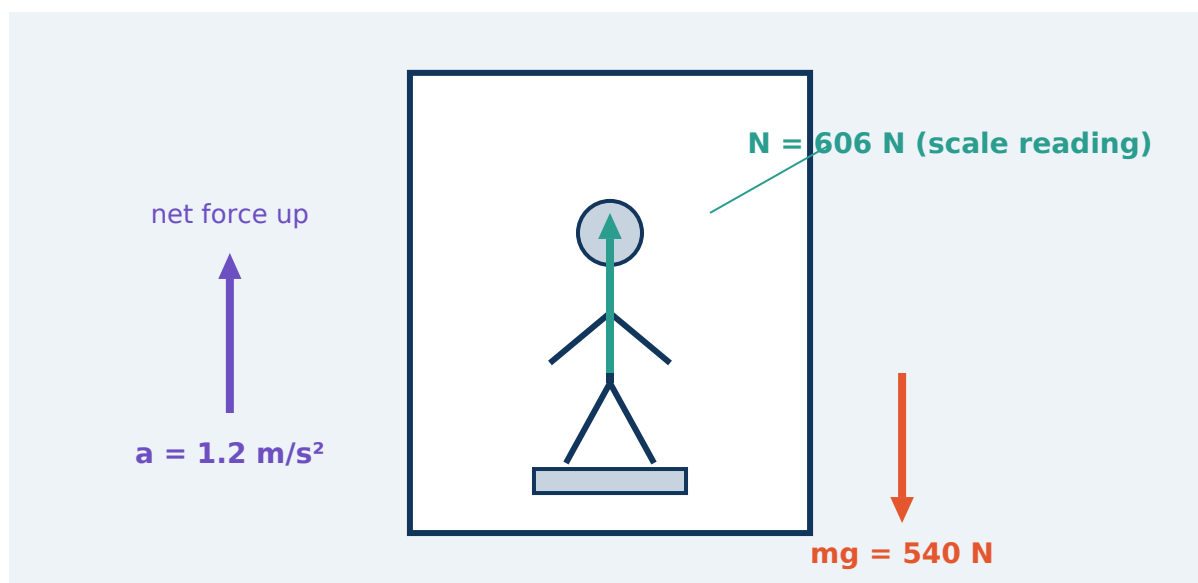
Vertical: $N + F \sin 30^\circ = mg$, so $N = 196.2 - 25 = \mathbf{171 \text{ N}}$, less than the weight because the rope helps to hold the block up.

Worked example

Emma, 55 kg, stands on a scale in an elevator that accelerates upward at 1.2 m/s^2 .

Weight = $55 \times 9.81 = 540 \text{ N}$ downward. Taking up as positive: $N - mg = ma$.

$N = m(g + a) = 55 \times (9.81 + 1.2) = \mathbf{606 \text{ N}}$, so the scale reads about 12 % more than usual.

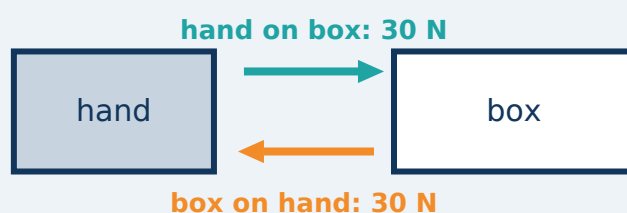


Net force upward: $606 \text{ N} - 540 \text{ N} = 66 \text{ N}$ (to 2 significant figures), so the 55 kg passenger accelerates upward.

What does Newton's third law say?

Key law

Third law: whenever object A exerts a force on object B, B exerts a force on A that is equal in magnitude, opposite in direction and of the same type. The two forces act on different objects.



equal size, opposite direction, acting on different objects

A pair of forces always acts on two different objects, so the two arrows never appear on the same free-body diagram.

Force on one object	Third-law partner
Earth pulls the book down (gravity)	book pulls Earth up (gravity)
hand pushes the wall	wall pushes the hand
tyre pushes the road backward	road pushes the tyre forward
rope pulls the crate	crate pulls the rope

Common mistake

Students say the weight of a book on a table and the normal force are a third-law pair because they are equal and opposite. They are not: both act on the book, and the partner of the normal force is the force of the book on the table.

Lina's tip

Write every force as "force of X on Y". The word after "on" tells you which diagram it belongs to, and it stops you putting a third-law partner on the same diagram.

Key points to remember

- First law: $\Sigma F = 0$ means constant velocity.
- Second law: $\Sigma F = ma$, with the force in newtons ($1 \text{ N} = 1 \text{ kg} \cdot \text{m/s}^2$).
- Weight $W = mg$, with $g = 9.81 \text{ N/kg}$ near Earth.
- Third law: equal, opposite forces of the same type on two different objects.
- Draw one object per diagram and show only forces exerted on it.

Free-body diagrams and net force problems: frequently asked questions

What is a free-body diagram?

It is a sketch of one chosen object, drawn as a dot or box, with an arrow for every external force acting on it. Arrow lengths show relative size and directions show the direction of each force.

Why do third-law forces not cancel each other?

The two forces act on different objects. Cancelling only happens for forces on the same object, so a third-law pair never appears on the same free-body diagram.

Is the mass of an object different from its weight?

Yes. Mass in kilograms measures how much matter and how much inertia the object has. Weight in newtons is the gravitational force on it and equals mg , so it changes with location.

What does a scale really measure in an elevator?

A scale measures the normal force it exerts on the person. When the elevator accelerates upward the normal force is larger than the weight, and when it accelerates downward it is smaller.

How do you use $\Sigma F = ma$ with a diagram?

Choose directions, resolve forces into components, add them with signs to get ΣF on each axis, and divide by the mass. Where there is no motion in a direction, the sum of forces there is zero.