

Impulse, momentum and force-time graphs

AP Physics 1 (algebra-based) · Lesson

Quick answer: Linear momentum is the product of mass and velocity, $p = mv$, a vector in kg m/s. Impulse is the net force multiplied by the time it acts, $J = F\Delta t$, and equals the change in momentum, $F\Delta t = \Delta p$. On a force-time graph, the area under the curve gives the impulse.

Level: AP Physics 1 (algebra-based) · **Curriculum:** AP P1 Unit 4

What is linear momentum?

A cricket ball and a tennis ball can travel at the same speed, yet the cricket ball is much harder to stop. Momentum captures this: it grows with both mass and velocity. Because velocity has a direction, momentum is a vector that points the way the object moves.

Definition

Linear momentum is the product of an object's mass and its velocity: $p = mv$. Its SI unit is kg m/s. Momentum is a vector, so in one dimension you must choose a positive direction and give each momentum a sign.

Object	Mass (kg)	Speed (m/s)	Momentum (kg m/s)
Cricket ball	0.16	30	4.8
Cyclist with bicycle	80	5.0	4.0×10^2
Loaded minibus	3000	2.0	6.0×10^3

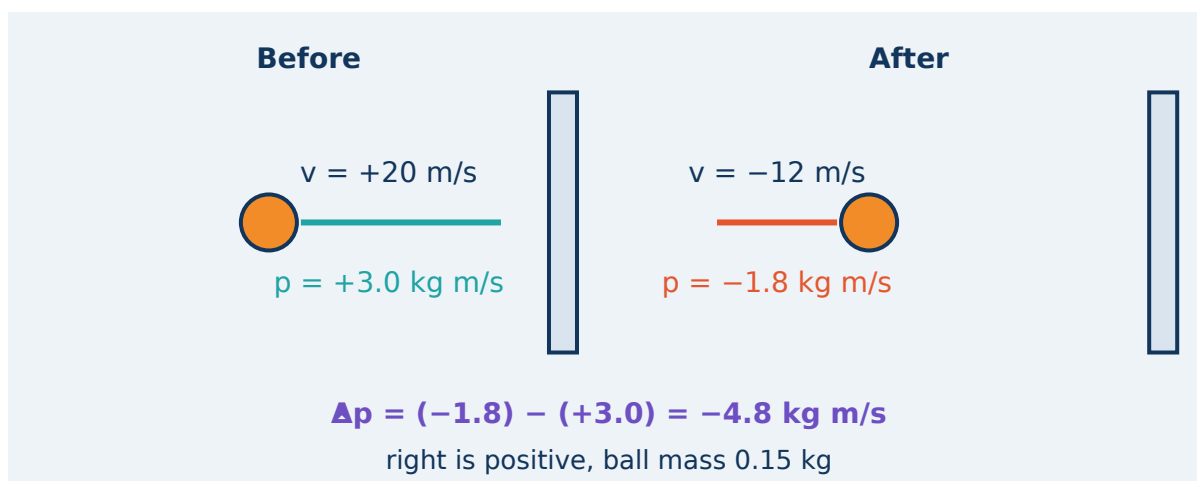
What is impulse and how does it change momentum?

To change momentum you need a net force that acts for some time. The product of the two is called impulse. A small force acting for a long time and a large force acting for a short time can produce the same change.

Key law

Impulse-momentum theorem: $J = F_{\text{net}}\Delta t = \Delta p = m(v_f - v_i)$. Impulse J is measured in N s, which is the same unit as kg m/s. For a force that changes with time, the impulse is the area under the force-time graph.

The theorem is Newton's second law written in a more useful form, because it handles brief, violent contacts such as bat and ball where the force is not constant. Figure 1 shows a rebound, where the sign of velocity flips and the change in momentum is larger than the momentum itself.



The sign convention matters: the rebound reverses the velocity, so the change in momentum is larger than the initial momentum.

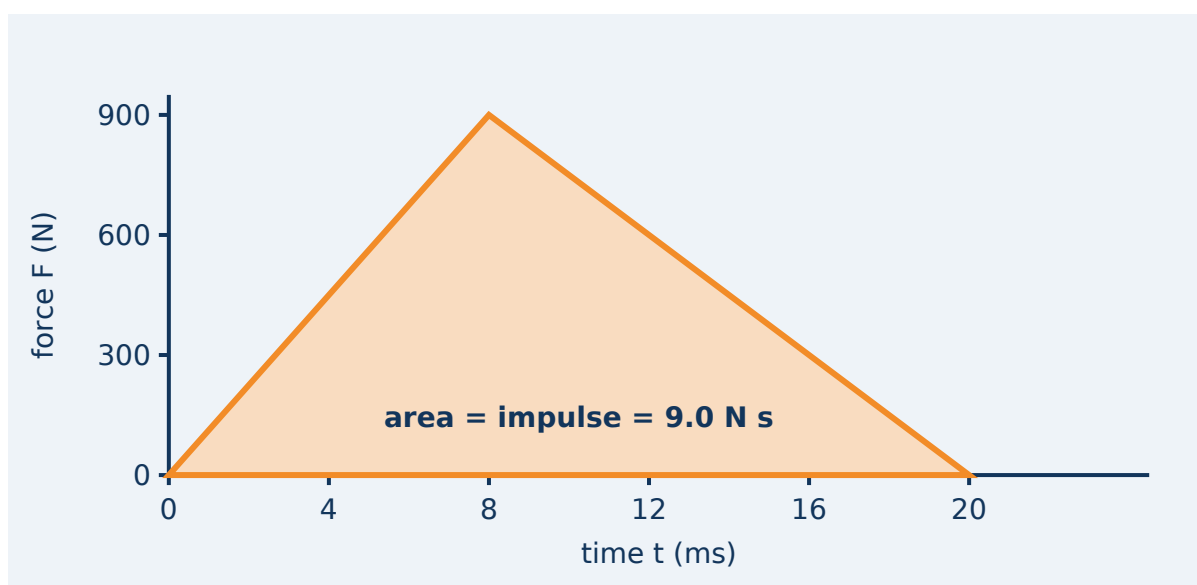
Worked example 1

The 0.15 kg ball in Figure 1 touches the wall for 0.010 s. Find the average force the wall exerts on it.

Method: take right as positive. $\Delta p = m(v_f - v_i) = 0.15 \text{ kg} \times (-12 - 20) \text{ m/s} = -4.8 \text{ kg m/s}$. Then $F_{\text{avg}} = \Delta p / \Delta t = -4.8 \text{ N s} \div 0.010 \text{ s} = -4.8 \times 10^2 \text{ N}$. The force has magnitude 480 N and points left, away from the wall.

How do you read a force-time graph?

Real contact forces rise, peak and fall. Instead of guessing an average, measure the area between the curve and the time axis. Triangles give $\frac{1}{2} \times \text{base} \times \text{height}$, rectangles give base $\times$ height, and a curved shape can be estimated by counting squares. Area below the axis counts as negative impulse.



A football kick: the area under the curve is the impulse. $\text{Area} = \frac{1}{2} \times 0.020 \text{ s} \times 900 \text{ N} = 9.0 \text{ N s}$.

Worked example 2

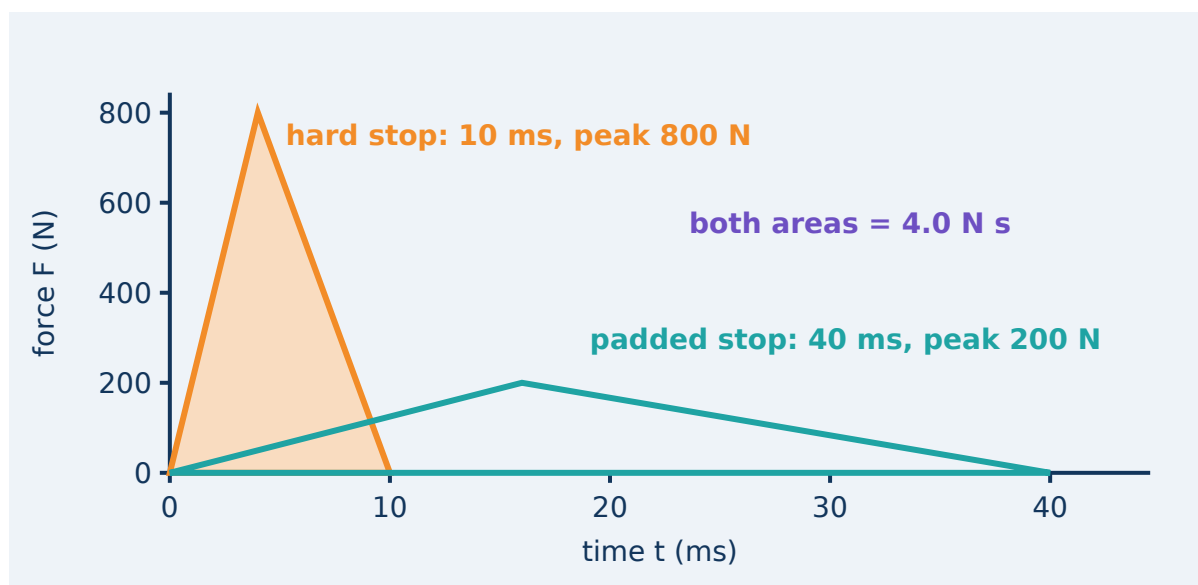
A football of mass 0.45 kg is kicked from rest. The force on it follows the triangle in Figure

2. Find its launch speed.

Method: $\text{area} = \frac{1}{2} \times 0.020 \text{ s} \times 900 \text{ N} = 9.0 \text{ N s}$, so $J = 9.0 \text{ N s}$. Since $v_i = 0$, $J = mv_f$ and $v_f = 9.0 \div 0.45 = \mathbf{20 \text{ m/s}}$.

Why do airbags and padding reduce injuries?

If the momentum change is fixed, then $F_{\text{avg}} = \Delta p / \Delta t$ tells you that a longer contact time means a smaller average force. A crumple zone, a padded glove and bending knees on landing all stretch the time. In Figure 3 the two curves enclose the same area, so the same momentum is removed, but the padded stop has one quarter of the peak force.



Both stops remove the same momentum, 4.0 kg m/s , so both curves enclose the same area. Spreading the stop over more time lowers the force.

Worked example 3

A fielder stops a 0.16 kg ball travelling at 25 m/s . Compare the average force if the hands stop it in 0.010 s with hands pulled back so that it stops in 0.040 s .

Method: $\Delta p = 0.16 \times 25 = 4.0 \text{ kg m/s}$ in both cases. Hard hands: $F = 4.0 \div 0.010 = 400 \text{ N}$. Giving with the ball: $F = 4.0 \div 0.040 = \mathbf{1.0 \times 10^2 \text{ N}}$, only a quarter as large.

Common mistake

Forgetting the sign when a ball bounces. If a ball moves at $+20 \text{ m/s}$ and returns at 12 m/s the other way, Δv is -32 m/s , not -8 m/s . Treating the speeds as positive numbers underestimates the impulse of a rebound, which is always larger than that of a stop from the same speed.

Lina's tip

Write the positive direction on your diagram before any numbers. Then give every initial and final velocity a sign. Most lost marks on impulse problems come from a missing minus sign.

Key points to remember

- Momentum: $p = mv$, a vector in kg m/s
- Impulse-momentum theorem: $F_{\text{net}}\Delta t = \Delta p = m(v_f - v_i)$
- Impulse is measured in N s, and $1 \text{ N s} = 1 \text{ kg m/s}$
- The area under a force-time graph is the impulse (areas below the axis are negative)
- For a fixed Δp , a longer contact time gives a smaller average force

Impulse, momentum and force-time graphs: frequently asked questions

What is the difference between impulse and momentum?

Momentum is a property of a moving object at one instant, $p = mv$. Impulse is the effect of a net force acting over a time interval and equals the change in momentum between two instants. They share the unit $\text{N s} = \text{kg m/s}$ but describe different ideas.

Why is the impulse bigger when a ball bounces than when it stops?

The velocity changes from positive to negative, so the difference $v_f - v_i$ is larger than the starting speed alone. A ball stopping from 10 m/s changes by 10 m/s, whereas a perfect rebound changes by 20 m/s, doubling the impulse.

Can the impulse on an object be negative?

Yes. Impulse is a vector. If the net force points in the negative direction, or the area of a graph lies below the time axis, the impulse and the change in momentum are negative.

How do you find impulse when the force changes in a curve?

Find the area under the curve. Split the shape into triangles and rectangles, or count the squares on the graph paper and multiply by the value of one square. The result in N s equals the change in momentum.

Does a longer contact time change the impulse?

No. The impulse is fixed by the change in momentum. A longer contact time only spreads the same impulse over more time, so the average force is smaller. That is the principle behind airbags, helmets and crumple zones.