Changes in momentum

4.5.7.3 · Forces · revision notes

A force acting on an object changes its momentum: force equals the rate of change of momentum, F = m Δv ÷ Δt (on the equations sheet). You need to use this equation and explain how air bags, seat belts, crash mats, cushioned playground surfaces and cycle helmets reduce forces. This is Higher tier content, in GCSE Physics only, not in Combined Science.

Key facts

- F = m Δv ÷ Δt (on the equations sheet)
- Force = rate of change of momentum
- Same change in momentum, longer time → smaller force
- m Δv = change in momentum
- Units: F in N, m in kg, Δv in m/s, Δt in s
- Safety features: seat belts, air bags, crash mats, cushioned playground surfaces, cycle helmets (and crumple zones)

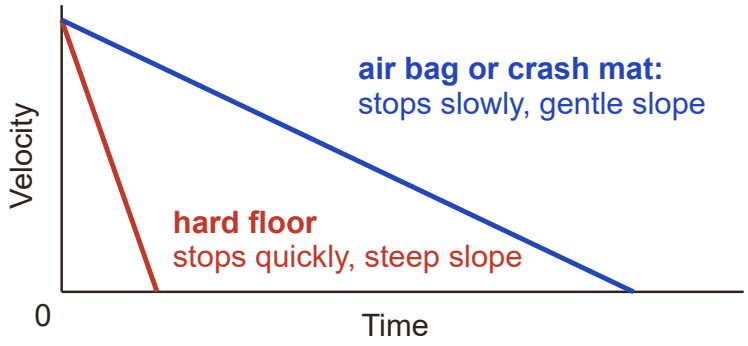
Notes

Force and change in momentum

- When a force acts on an object that is moving, or able to move, a change in momentum occurs.
- The equations F = m a and a = Δv ÷ Δt combine to give **F = m Δv ÷ Δt** (on the equations sheet).
- m Δv is the **change in momentum**, so force = change in momentum ÷ time taken. Force equals the **rate of change of momentum**.
- F in N, m in kg, Δv in m/s, Δt in s.

A longer time means a smaller force

- For the same change in momentum, the longer the time taken for the change, the smaller the force.
- Example: a 70 kg person stopping from 15 m/s has a change in momentum of 70 × 15 = 1050 kg m/s. Stopping in 0.05 s needs a force of 21 000 N; stopping in 0.5 s needs only 2100 N.



Same change in momentum. A longer stopping time gives a smaller deceleration, so a smaller force.

- Smaller forces on the body mean less chance of serious injury.

Safety features

- **Seat belts** stretch slightly, so the passenger takes longer to stop.
- **Air bags** inflate and then squash as the person hits them, increasing the time for the head and chest to stop.
- **Gym crash mats** and **cushioned playground surfaces** squash when you land on them, increasing the time taken to stop.
- **Cycle helmets** have a crushable foam layer that increases the time for the head to stop. Crumple zones in cars work in the same way.
- In each case: longer time for the momentum to change → smaller rate of change of momentum → smaller force.

How to answer each type of question

Calculate force from a change in momentum

3 marks | Grade 6

1. Calculate the change in momentum, m Δv.
2. Divide by the time taken (in seconds).
3. Give the answer in N.

Example. A footballer kicks a stationary ball of mass 0.45 kg. The ball leaves her foot at 20 m/s. Her foot is in contact with the ball for 0.015 s.
Calculate the average force on the ball.

Model answer.

change in momentum = 0.45 × 20 = 9.0 kg m/s (1)

F = 9.0 ÷ 0.015 (1)

F = 600 N (1)

Show that force = rate of change of momentum

2 marks | Grade 7

1. Substitute a = (v − u) ÷ t into F = m a.
2. Identify m v − m u as the change in momentum.

Example. Use the equations F = m a and a = (v − u) ÷ t to show that force is equal to the rate of change of momentum.

Model answer.

F = m (v − u) ÷ t (1)

m (v − u) = m v − m u = change in momentum, so F = change in momentum ÷ time taken, which is the rate of change of momentum (1).

Explain how a safety feature works

4 marks | Grade 7

1. Say that the person's momentum must change (to zero).
2. Say that the feature increases the time taken for this change.
3. So the rate of change of momentum is smaller.
4. So the force on the person is smaller.

Example. Explain how an air bag reduces the risk of injury to a driver in a crash.

Model answer.

In the crash, the driver's momentum changes to zero	(1).
The air bag increases the time taken for the driver's head and chest to stop	(1).
So the rate of change of momentum is smaller	(1)
so the force on the driver is smaller	(1).

Compare forces for different stopping times

4 marks | Grade 8

1. Calculate the change in momentum once.
2. Divide it by each time.
3. Compare the two forces.

Example. A gymnast of mass 50 kg lands at 6.0 m/s. On a hard floor she stops in 0.10 s. On a crash mat she stops in 0.40 s.
Calculate how much smaller the average force on her is when she lands on the crash mat.

Model answer.

change in momentum = 50 × 6.0 = 300 kg m/s	(1)
hard floor: F = 300 ÷ 0.10 = 3000 N	(1)
crash mat: F = 300 ÷ 0.40 = 750 N	(1)
The force is 2250 N smaller (a quarter as big) on the mat	(1).

Rearrange to find the time taken

3 marks | Grade 8

1. Calculate the change in momentum.
2. Rearrange: $\Delta t = m \Delta v \div F$.
3. Give the answer in seconds.

Example. A cycle helmet is designed so that the force on a rider's head is no more than 2000 N. The head has a mass of 5.0 kg and is moving at 6.0 m/s.
Calculate the minimum time the helmet must take to stop the head.

Model answer.

change in momentum = 5.0 × 6.0 = 30 kg m/s	(1)
$\Delta t = 30 \div 2000$	(1)
$\Delta t = 0.015$ s	(1)

Don’t lose marks

- Saying safety features 'absorb the force' or 'absorb the momentum'. Say that they increase the time taken for the momentum to change, so the force is smaller.
- Saying an air bag reduces the change in momentum. The change in momentum is the same; the time taken is longer.
- Using a time in milliseconds without converting to seconds (15 ms = 0.015 s).
- Forgetting that if an object bounces back, its change in velocity (and momentum) is bigger than if it just stops.
- Writing that a safety feature 'slows down time' or just 'reduces the impact'. Say it increases the time taken to stop, so the force is smaller.

More tips

Memory tricks

- Longer time, smaller force: every safety-feature question uses this idea.
- Squash, stretch or crumple = more time = less force.
- $F \times \Delta t = m \Delta v$: the crash fixes the change in momentum, so the only way to reduce the force is to increase the time.

Exam technique

- $F = m \Delta v \div \Delta t$ is on the equations sheet, but you must be able to explain it in words for safety-feature questions.
- Use the full chain: increases the time → decreases the rate of change of momentum → decreases the force.
- In comparison calculations, work out the change in momentum once, then divide by each time.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 6

State that a force changes momentum

When a force acts on an object that is moving, or able to move, its momentum changes.

Grade 6

Calculate force from a change in momentum

Force = change in momentum ÷ time taken; the equation is on the equations sheet.

Grade 7

Derive the rate-of-change-of-momentum equation

Substitute $a = \Delta v \div \Delta t$ into $F = m\,a$ to get $F = m\,\Delta v \div \Delta t$.

Grade 7

Explain how safety features reduce injury

They increase the time taken for the momentum to change, so the force is smaller.

Grade 8

Rearrange to find a time or velocity change

$\Delta t = m\,\Delta v \div F$ and $\Delta v = F\,\Delta t \div m$.

Grade 8

Compare forces for different stopping times

The same change in momentum over a longer time gives a proportionally smaller force.

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