1.2 Impact forces

Learning objectives:

- What happens to the impact force (and why?) if the duration of impact is reduced?
- How do we calculate $\Delta(mv)$ for a moving object which stops or reverses?
- What happens to the momentum of a ball when it bounces off a wall?

Specification reference: 3.4.1

Figure 1 *A golf ball impact*

A sports person knows that the harder a ball is hit, the further it travels. The impact changes the momentum of the ball in a very short time when the object exerting the impact force is in contact with the ball.

- If the ball is initially stationary and the impact causes it to accelerate to speed v in time t, the gain of momentum of the ball due to the impact $= mv$, where m is the mass of the ball.

  Therefore, the force of the impact $F = \dfrac{\text{change of momentum}}{\text{contact time}} = \dfrac{mv}{t}$

- If the ball is moving with an initial velocity, u, and the impact changes its velocity to v in time t, the change of momentum of the ball $= mv - mu$.

  Therefore, the force of impact $F = \dfrac{\text{change of momentum}}{\text{contact time}}$,

$$F = \frac{mv - mu}{t}$$

Link

Use of $F = ma$ and $a = \dfrac{v-u}{t}$ is another way to calculate an impact force.

See *AS Physics*, Topic 9.5.

Worked example:

A ball of mass 0.63 kg initially at rest was struck by a bat which gave it a velocity of 35 m s^{-1}. The contact time between the bat and ball was 25 ms. Calculate:

a the momentum gained by the ball,

b the average force of impact on the ball.

(**Note** The 'm' in ms stands for milli.)

Solution

a Momentum gained $= 0.63 \times 35 = 22\,\text{kg m s}^{-1}$

b Impact force $= \dfrac{\text{gain of momentum}}{\text{contact time}} = \dfrac{22}{0.025} = 880\,\text{N}$

Application and How science works

Vehicle safety reminders

The AS specification looks at the physics of vehicle safety features such as crumple zones, seatbelts, collapsible steering wheels, and airbags. These and other features such as side-impact bars are all designed to lessen the effect of an impact on people in the vehicle. As explained at AS level, the essential idea is to increase the time taken by an impact so the acceleration or deceleration is less and therefore the impact force is less. The result is the same using the idea of momentum; for a given change of momentum, the force is reduced if the impact time is increased. However, as explained in Topic 1.3, the ideas can be developed much further by using the concept of momentum.

Force–time graphs for impacts

The variation of an impact force with time on a ball can be recorded using a force sensor connected using suitably long wires or a radio link to a computer. The force sensor is attached to the object (e.g. a bat) that causes the impact. Because equal and opposite forces act on the ball, the force on the ball due to the bat varies in exactly the same way as the force on the bat due to the ball. The variation of force with time is displayed on the computer screen.

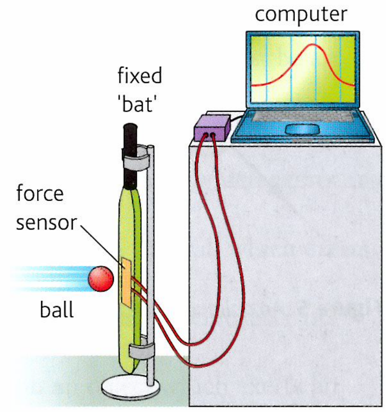
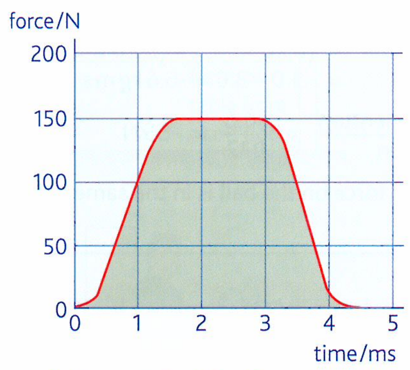


Figure 2 *Investigating an impact force on a ball*

Figure 3 shows a typical force–time graph for an impact. The graph shows that the impact force increases then decreases during the impact. As explained in Topic 1.2, the area under the graph is equal to the change of momentum. The average force of impact can be worked out from the change of momentum divided by the contact time.



area under curve = 9 blocks

Ft for 1 block = 50 N × 1 ms

= 5.0×10^{-2} N s

change of momentum

= $9 \times 5.0 \times 10^{-2}$

= 0.45 N s

Figure 3 *Force against time for an impact*

Rebound impacts

When a ball hits a wall and rebounds, its momentum changes direction due to the impact. If the ball hits the wall normally, it rebounds normally so the direction of its momentum is reversed. The velocity and therefore the momentum after the impact is in the opposite direction to the velocity before the impact and therefore has the opposite sign. Figure 4 shows the idea.

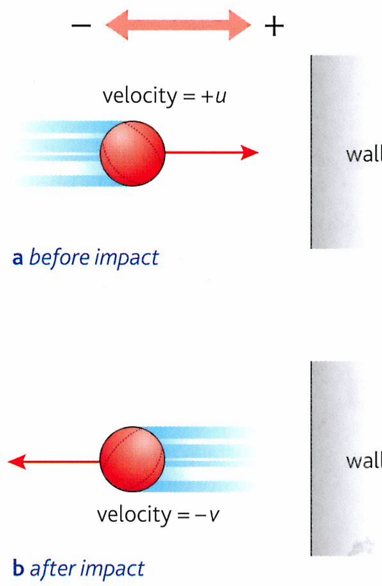


Figure 4 *A rebound*

Suppose the ball hits the wall normally with an initial speed u and it rebounds at speed v in the opposite direction. Since its direction of motion reverses on impact, a sign convention is necessary to represent the two directions. Using + for 'towards the wall' and – for 'away from the wall', its initial momentum = $+mu$, and its final momentum = $-mv$.

Therefore,

its change of momentum = final momentum – initial momentum

$$= (-mv) - (mu)$$

$$\text{The impact force } F = \frac{\text{change of momentum}}{\text{contact time}} = \frac{(-mv) - (mu)}{t}$$

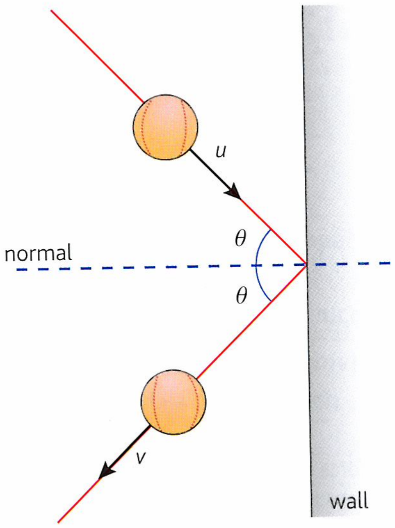


Figure 5 *An oblique impact*

Notes:

1 If there is no loss of speed on impact, then $v = u$ so the impact force

$$F = \frac{(-mu) - (mu)}{t} = \frac{-2mu}{t}$$

2 If the impact is oblique (i.e. the initial direction of the ball is not perpendicular to the wall), the normal components of the velocity must be used. For an impact in which the initial and final direction of the ball are at the same angle θ to the normal and there is no loss of speed (i.e. $u = v$), the normal component of the initial velocity is $+u\cos\theta$ and the normal component of the final velocity is $-u\cos\theta$. The change of momentum of the ball is therefore $-2\,mu\cos\theta$.

Worked example:

A tennis ball of mass 0.20 kg moving at a speed of $18\,\text{m}\,\text{s}^{-1}$ was hit by a bat, causing the ball to go back in the direction it came from at a speed of $15\,\text{m}\,\text{s}^{-1}$. The contact time was 0.12 s. Calculate:

a the change of momentum of the ball,

b the impact force on the ball.

Solution

a Mass of ball $m = 0.20$ kg, initial velocity $u = +18\,\text{m}\,\text{s}^{-1}$, final velocity $= -15\,\text{m}\,\text{s}^{-1}$.
Change of momentum $= mv - mu = (0.20 \times -15) - (0.20 \times 18)$
$= -3.0 - 3.6 = -6.6\,\text{kg}\,\text{m}\,\text{s}^{-1}$

b Impact force $= \dfrac{\text{change of momentum}}{\text{time taken}} = \dfrac{-6.6}{0.12} = -55\,\text{N}$

Note: The minus sign indicates the force on the ball is in the same direction as velocity after the impact.

Summary questions

1 A 2000 kg lorry reversing at a speed of $0.80\,\text{m}\,\text{s}^{-1}$ backs accidentally into a steel fence. The fence stops the lorry 0.5 s after the lorry first makes contact with the fence. Calculate:

a the initial momentum of the lorry,

b the force of the impact.

2 A car of mass 600 kg travelling at a speed of $3.0\,\text{m}\,\text{s}^{-1}$ is struck from behind by another vehicle. The impact lasts for 0.40 s and causes the speed of the car to increase to $8.0\,\text{m}\,\text{s}^{-1}$. Calculate:

a the change of momentum of the car due to the impact,

b the impact force.

3 A molecule of mass 5.0×10^{-26} kg moving at a speed of $420\,\text{m}\,\text{s}^{-1}$ hits a surface at right angles to the surface and rebounds at the same speed in the opposite direction in an impact lasting 0.22 ns. Calculate:

a the change of momentum,

b the force on the molecule.

4 Repeat the calculation in Q3 for a molecule of the same mass at the same speed which hits the surface at 60° to the normal and rebounds without loss of speed at 60° to the normal as shown in Figure 6. You will need to work out the component of the molecule's velocity parallel to the normal before and after the impact. Assume the contact time is the same.

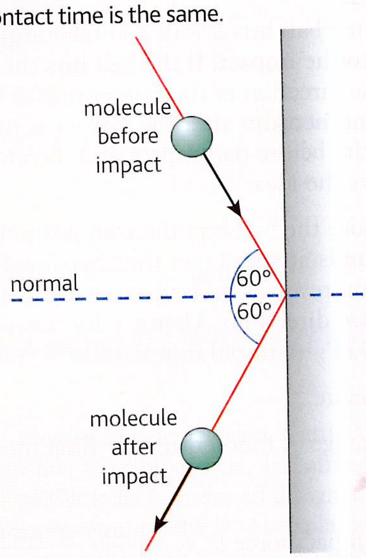


Figure 6