Chapter 2
Collisions and explosions

Worksheet

Worked examples

Practical: Using the conservation of momentum to determine the speed of an air-rifle pellet – a demonstration

End-of-chapter test

Marking scheme: Worksheet

Marking scheme: End-of-chapter test

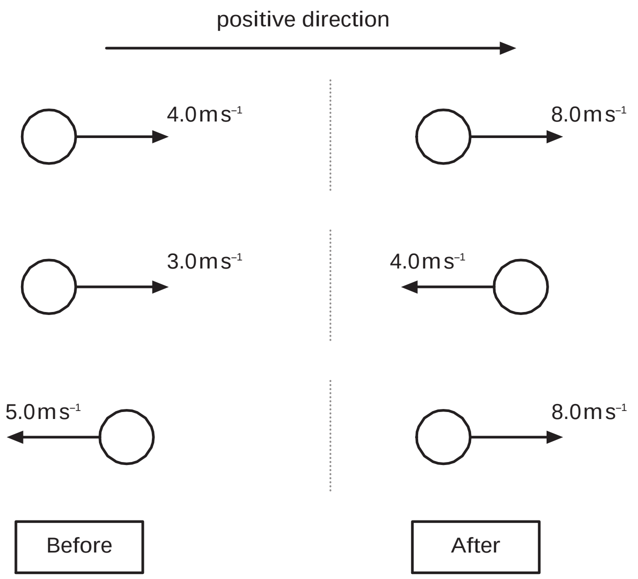
Worksheet

Intermediate level

1 Define linear momentum and state its SI unit. [2]

2 A bumper car collides at right-angles with a metal barrier and rebounds at the same speed. A student suggests that the change in momentum of the car is zero. Explain why the student is wrong. [2]

3 Each diagram shows a 2.0 kg object before and after a collision. Calculate the change in momentum of the object in each case.



a [2]

b [2]

c [2]

4 A 0.30 g fly moving at 1.5 m s^{-1} is trapped by a spider's web. The fly comes to rest in a time of 0.40 s. Calculate the magnitude of:

a the change in momentum of the fly; [2]

b the average force exerted by the web on the fly. [3]

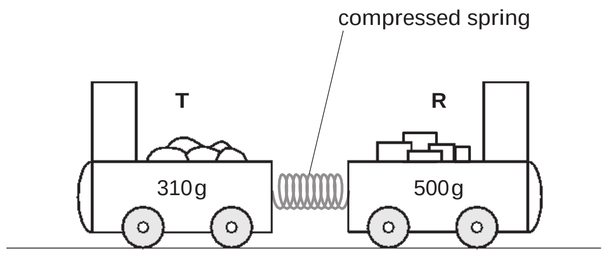
5 A 850 kg cannon fires a 20 kg shell at a velocity of 180 m s^{-1}.

a Calculate the final momentum of the shell. [2]

b What is the magnitude of the momentum of the cannon immediately after the shell is fired? (You may assume that the cannon is initially at rest.) [2]

c Calculate the recoil velocity *V* of the cannon. [3]

6 The diagram shows two toy trains **T** and **R** held in place on a level track against the force exerted by the compressed spring.



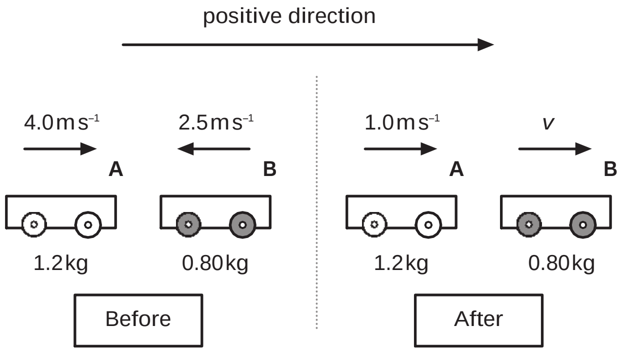
When the trains are released, **R** moves to the right at a speed of 3.8 m s^{-1}. The spring takes 0.25 s to uncoil to its natural length. Calculate:

a the velocity of train **T**; [4]

b the average force exerted by the spring on each train. [4]

Higher level

7 The diagram below shows the initial state of two trolleys **A** and **B** before colliding and the final state immediately after the collision.



Calculate the final velocity *v* of **B**. [4]

8 A ball of mass 210 g moving at a speed of 23 m s^{-1} hits a wall at right-angles and rebounds at the same speed. The ball is in contact with the wall for 0.31 s.

a Calculate the change in momentum of the ball. [2]

b Is the momentum of the ball conserved? Explain your answer. [2]

c Calculate the magnitude of the average force acting on the ball. [3]

9 A bullet of mass 30 g is fired at a speed of 140 m s^{-1} into a stationary block of wood of mass 460 g. The bullet becomes embedded inside the wood.

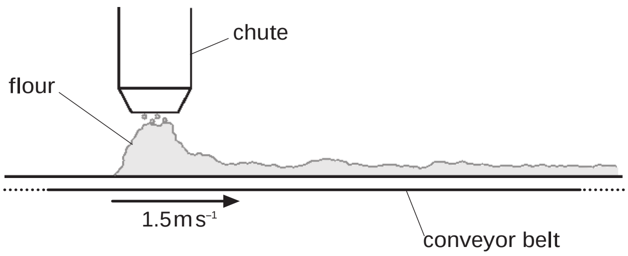
a Calculate the common speed of the block of wood and the bullet after the impact. [4]

b Calculate the initial kinetic energy of the bullet and the final kinetic energy of the block of wood and the embedded bullet. [3]

c Use your answers to **b** to suggest whether the collision between the bullet and the block of wood is inelastic or elastic. [1]

Extension

10 The diagram shows flour falling onto a horizontally moving conveyor.



The flour falls vertically onto the conveyor belt at a constant rate of 3.2 kg s^{-1}. The conveyor belt is moving at a constant speed of 1.5 m s^{-1}. Calculate the horizontal force required to keep the belt moving. [4]

11 A stationary radioactive nucleus of mass *M* ejects an -particle of mass *m* at a speed of 2.0 10^7 m s^{-1}. Given *M* = 55*m*, calculate the kinetic energy of the -particle as a percentage of the final total kinetic energy. [6]

Total: $\frac{\quad}{59}$ Score: %

Worked examples

Example 1

A car of mass 800 kg is travelling along a level road at a velocity of $4.0\,\mathrm{m\,s^{-1}}$. The driver presses on the accelerator for a time of 15 s. During this period, a constant force of 400 N is exerted on the car. Use Newton's second law to determine the final velocity v of the car. (You may assume that the effect of air resistance is negligible.)

According to Newton's second law:

$$\text{force} = \frac{\text{change in momentum}}{\text{time}}$$

$$400 = \frac{(800v) - (800 \quad 4.0)}{15}$$

$$F = \frac{p}{t}$$

$$400 \quad 15 = 800v - 3200$$

$$800v = 6000 + 3200$$

$$v = \frac{9200}{800} = 11.5\,\mathrm{m\,s^{-1}} \quad 12\,\mathrm{m\,s^{-1}}$$

Tip

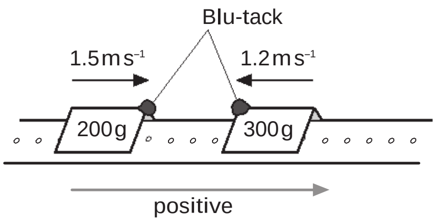
You may use $F = ma$ and $v = u + at$ to get the answer:

$$a = \frac{F}{m} = \frac{400}{800} = 0.50\,\mathrm{m\,s^{-2}}$$

$$v = u + at = 4.0 + (0.50 \quad 15) = 11.5 \;1 \;\; 2\,\mathrm{m\,s^{-1}}$$

Example 2

The diagram shows two gliders on a linear air track about to collide. After the collision, the gliders become stuck and move together. Calculate the speed v of the gliders immediately after the collision. What is the direction of travel after the collision?



Momentum is conserved in all collisions. Therefore:

total initial momentum = total final momentum

$$(0.200 \quad 1.5) + (0.300 \quad -1.2) = (0.500 \quad v) \; 0.500v \; -$$

0.06

The momentum of the 300 g glider is negative because it is moving in the 'opposite' direction.

$$v = -\frac{0.06}{0.500} = -0.12\,\mathrm{m\,s^{-1}}$$

The minus sign means that after the collision the gliders move to the **left**.

Tip

When solving problems to do with the conservation of momentum, assign a positive sign to one of the directions. In the example above:

to the **right** **positive** direction

Practical

Using the conservation of momentum to determine the speed of an air-rifle pellet – a demonstration

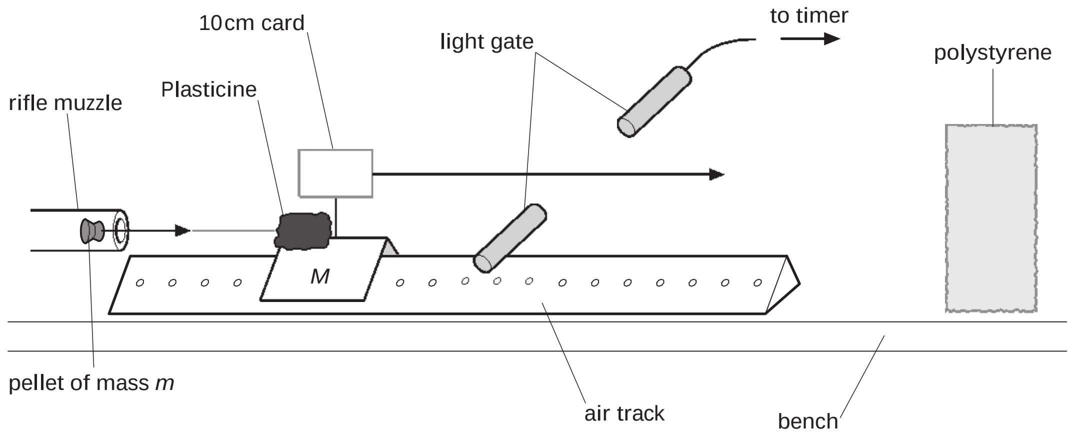
Safety

All students should be behind a safety screen. It is also advisable to use a polystyrene block just in case the shooter (teacher) misses the Plasticine. Teachers and technicians should follow their school and departmental safety policies and should ensure that the employer's risk assessment has been carried out before undertaking any practical work.

Apparatus

- linear air track
- air track glider
- Plasticine (about 30 g)
- 10 cm card
- light gate
- timer
- air rifle
- digital balance
- polystyrene block
- safety screen

Introduction



The conservation of linear momentum is discussed on page 13 of *Physics 2*. This important principle is used in the experiment described here to determine the speed of an air-rifle pellet. Secure some Plasticine onto the glider (see diagram). The amount of Plasticine is such that the fired pellet gets embedded within the Plasticine and does not come out. According to the principle of conservation of momentum, we have:

initial momentum of pellet = final momentum of pellet and glider (with Plasticine)

Therefore:

$$mv = (M + m)V$$

where m is the mass of the pellet, v is the velocity of the pellet from the air rifle, M is the mass of the glider, card and Plasticine, and V is the common velocity of the glider and the embedded pellet immediately after the collision.

The speed v of the pellet is given by:

$$v = \frac{M + m}{m} \quad V$$

Procedure

1 Measure the total mass M of the glider (with the card and the Plasticine) and also the mass m of the pellet.

2 Ensure the glider is initially at rest. Place the rifle muzzle close to the Plasticine and fire the pellet.

3 The glider will travel through the light gate. Record the time t taken for the 10 cm card to pass through the light gate.

4 Determine the common speed V of the glider and the embedded pellet using:

$$V = \frac{0.10}{t} \text{ m s}^{-1}$$

5 Calculate the speed v of the pellet using:

$$v = \frac{M+m}{m} \quad V$$

6 Estimate the uncertainty in your answer for the speed of the pellet.

Guidance for teachers

You can adapt this experiment to determine the speed of a dart fired from a toy gun.

End-of-chapter test

Answer all questions.

1 Two cars are involved in a head-on collision.

a State two quantities conserved in the collision. [2]

b The collision between the cars is described as an inelastic collision. Explain what is meant by an inelastic collision. [2]

2 **a** State Newton's second law. [1]

b A ball of mass 320 g hits the ground at right-angles at a speed of $15\,\mathrm{m\,s^{-1}}$ and rebounds vertically at a speed of $7.0\,\mathrm{m\,s^{-1}}$. The ball is in contact with the ground for a time of 0.16 s.

i Show that the change in momentum of the ball is about $7.0\,\mathrm{kg\,m\,s^{-1}}$. [2]

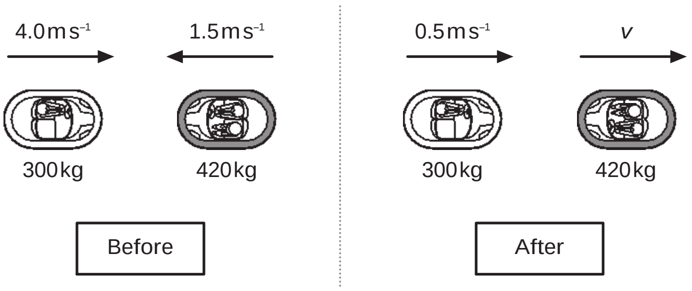
ii Calculate the average force on the ball during impact with the ground. [3]

3 A 2.8 tonne lorry moving at a speed of $30\,\mathrm{m\,s^{-1}}$ collides into the back of a stationary car of mass 800 kg on the hard shoulder of the motorway. During the collision, the lorry and the car get tangled together. Calculate:

a the common speed V of the tangled lorry and car; [4]

b the loss of kinetic energy in the collision. [3]

4 A bumper car of mass 300 kg moving at $4.0\,\mathrm{m\,s^{-1}}$ collides with another bumper car of mass 420 kg moving at $1.5\,\mathrm{m\,s^{-1}}$ in the opposite direction. After the collision, the speed of the 300 kg car decreases to $0.5\,\mathrm{m\,s^{-1}}$ but it carries on moving in the same direction (see diagram).



Determine the speed v and direction of the 420 kg bumper car after the collision. [4]

Total: $\frac{\quad}{21}$ Score: %

Marking scheme

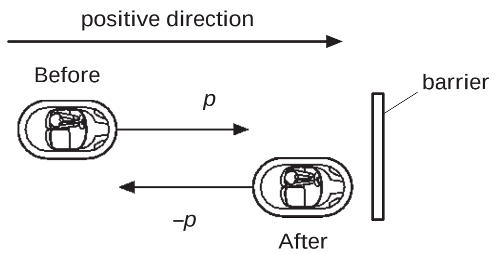
Worksheet

1 Momentum = mass   velocity [1]

SI unit of momentum is $\mathrm{kg\,m\,s^{-1}}$. [1]

2 Momentum is a vector quantity – it has both direction and magnitude. [1]

If the initial momentum of the car is $+p$, then its final momentum must be $-p$ (see diagram):



Change in momentum, p = final momentum – initial momentum

$p = -p - p = -2p$ (the change is not zero) [1]

3 **a** $p = (2.0\ \ \ 8.0) - (2.0\ \ \ 4.0)$ [1]; $p = +8.0\ \mathrm{kg\,m\,s^{-1}}$ [1]

b $p = (2.0\ \ \ -4.0) - (2.0\ \ \ 3.0)$ [1]; $p = -14\ \mathrm{kg\,m\,s^{-1}}$ [1]

c $p = (2.0\ \ \ 8.0) - (2.0\ \ \ -5.0)$ [1]; $p = +26\ \mathrm{kg\,m\,s^{-1}}$ [1]

4 **a** p = final momentum – initial momentum

$p = 0 - (0.30\ \ \ 10^{-3}\ \ \ 1.5)$ (the final momentum is zero) [1]

$p = 4.5\ \ \ 10^{-4}\ \mathrm{kg\,m\,s^{-1}}$ (magnitude only) [1]

b Newton's second law: $F = \dfrac{p}{t}$ [1]

$F = \dfrac{4.5\ \ \ 10^{-4}}{0.40}$ [1]; $F = 1.13\ \ \ 10^{-3}\ \mathrm{N}\ \ \ 1.1\ \ \ 10^{-3}\ \mathrm{N}$ [1]

5 **a** $p = mv = 20\ \ \ 180$ [1]

$p = 3.6\ \ \ 10^{3}\ \mathrm{kg\,m\,s^{-1}}$ [1]

b The momentum is conserved in this explosion. The momentum of the cannon is equal in magnitude but opposite in direction to that of the shell. [1]

Momentum of the cannon = $3.6\ \ \ 10^{3}\ \mathrm{kg\,m\,s^{-1}}$ [1]

c Using the answer from **b**, we have:

$850\ \ \ V = 3.6\ \ \ 10^{3}$ [1]

$V = \dfrac{3.6\ \ \ 10^{3}}{850}$ [1]; $V\ \ \ 4.2\ \mathrm{m\,s^{-1}}$ [1]

6 **a** Initial momentum = final momentum [1]

Moving towards the right is taken as the 'positive' direction.

$0 = (0.500\ \ \ 3.8) + (0.310\ \ \ v)$ (v is the velocity of **T**) [1]

$v = -\dfrac{0.500\ \ \ 3.8}{0.310}$ (the minus sign means that **T** moves to the left) [1]

$v = -6.13\ \mathrm{m\,s^{-1}}\ \ \ -6.1\ \mathrm{m\,s^{-1}}$ [1]

b $F = \frac{p}{t}$ [1]

$p = 0.500 \quad 3.8 = 1.9\,\mathrm{kg\,m\,s^{-1}}$, $\quad t = 0.25\,\mathrm{s}$ [1]

$F = \frac{1.9}{0.25}$ [1]; $F = 7.6\,\mathrm{N}$ [1]

7 Initial momentum = final momentum [1]

$(1.2 \quad 4.0) + (0.80 \quad -2.5) = (1.2 \quad 1.0) + (0.80 \quad v)$ [1]

$2.80 = 1.20 + 0.80v$

$v = \frac{2.80 \square 1.20}{0.80}$ [1]; $\quad v = 2.0\,\mathrm{m\,s^{-1}}$ (to the **right**) [1]

8 **a** $p = m \quad v = 0.210 \quad (-23 - 23)$ (original direction taken as 'positive') [1]

$p = -9.66\,\mathrm{kg\,m\,s^{-1}} \quad -9.7\,\mathrm{kg\,m\,s^{-1}}$ [1]

(The minus implies that the force exerted by the wall on the ball is in the opposite direction to its initial direction of travel.)

b The momentum of the ball itself is not conserved. [1]

The total momentum of the wall and the ball is conserved. The wall gains momentum equal to $9.7\,\mathrm{kg\,m\,s^{-1}}$ but because it is massive its velocity is negligible. [1]

c $F = \frac{p}{t}$ [1]

$p = -9.66\,\mathrm{kg\,m\,s^{-1}}$, $\quad t = 0.31\,\mathrm{s}$

$F = \frac{9.66}{0.31}$ (magnitude only) [1]; $\quad F \quad 31\,\mathrm{N}$ [1]

9 **a** Initial momentum of bullet = final momentum of bullet and block [1]

$0.030 \quad 140 = 0.490v$ (final total mass = 460 + 30 = 490 g) [1]

$v = \frac{0.030 \quad 140}{0.490}$ [1]; $\quad v = 8.57\,\mathrm{m\,s^{-1}} \quad 8.6\,\mathrm{m\,s^{-1}}$ [1]

b Kinetic energy $= \frac{1}{2}mv^2$ [1]

initial kinetic energy $= \frac{1}{2} \quad 0.030 \quad 140^2 = 294 \quad 290\,\mathrm{J}$ [1]

final kinetic energy $= \frac{1}{2} \quad 0.490 \quad 8.57^2 \quad 18\,\mathrm{J}$ (< 6% of initial KE) [1]

c The collision is **inelastic** because the kinetic energy is not conserved. [1]

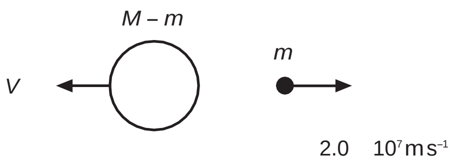
10 In a time interval of 1 s we have:

change in the horizontal momentum of the flour $\quad p = 3.2 \quad 1.5 = 4.8\,\mathrm{kg\,m\,s^{-1}}$ [2]

$t = 1.0\,\mathrm{s}$

Using Newton's second law $F = \frac{p}{t}$ [1]; so we have $F = \frac{4.8}{1.0} = 4.8\,\mathrm{N}$ [1]

11



Momentum is conserved so $p_{\text{nucleus} -} = p = p$ [1]

Kinetic energy KE = $\frac{1}{2}mv^2$ and momentum = mv so KE = $\frac{p^2}{2m}$

KE = $\frac{p^2}{2m}$ [1]

$$\text{KE}_{\text{nucleus} -} = \frac{p^2}{2(M-m)} = \frac{p^2}{2(55-1)m} = \frac{1}{54}\left(\frac{p^2}{2m}\right) \quad [1]$$

$$\text{KE}_{\text{total}} = \frac{p^2}{2m} + \frac{1}{54}\left(\frac{p^2}{2m}\right) = \frac{55}{54}\left(\frac{p^2}{2m}\right) \quad [1]$$

$$\text{ratio} = \frac{\text{KE}}{\text{KE}_{\text{total}}} = \frac{p^2}{2m} \Big/ \frac{55}{54}\left(\frac{p^2}{2m}\right) = \frac{54}{55} = 0.982 \quad 0.98 \quad [1]$$

The kinetic energy of the -particle is about 98% of the final total kinetic energy. [1]

Marking scheme

End-of-chapter test

1 **a** **Total energy** and **momentum** are always conserved in a collision. [2]

b The total kinetic energy of the cars after the collision is not the same as the total initial kinetic energy of the cars. [1]

Some of the kinetic energy is transformed to other forms like heat. [1]

2 **a** The rate of change of momentum of an object is directly proportional to the net force acting on the object and takes place in the direction of this force. [1]

b **i** Momentum, p = mass   velocity [1]

p = final momentum – initial momentum

$p = (0.320 \quad -7.0) - (0.320 \quad 15)$ [1]

$p = 7.04\,\mathrm{kg\,m\,s^{-1}} \quad 7.0\,\mathrm{kg\,m\,s^{-1}}$ (magnitude only)

ii $F = \frac{p}{t}$ [1]

$p = 7.0\,\mathrm{kg\,m\,s^{-1}}$, $t = 0.16\,\mathrm{s}$

$F = \frac{7.0}{0.16}$ [1]; $F \quad 44\,\mathrm{N}$ [1]

3 **a** Initial momentum of lorry = final momentum of lorry and car [1]

$2800 \quad 30 = (2800 + 800) \quad V$ [1]

$V = \frac{2800 \quad 30}{3600}$ [1]; $V = 23.3\,\mathrm{m\,s^{-1}} \quad 23\,\mathrm{m\,s^{-1}}$ [1]

b Kinetic energy = $\frac{1}{2}mv^2$ [1]

loss in kinetic energy $= \frac{1}{2} \quad 2800 \quad 30^2 - \frac{1}{2} \quad 3600 \quad 23.3^2$ [1]

loss in kinetic energy $\quad 2.8 \quad 10^5\,\mathrm{J}$ [1]

4 Total initial momentum = total final momentum [1]

$(300 \quad 4.0) + (420 \quad -1.5) = (300 \quad 0.5) + (420 \quad v)$ (positive to the right) [1]

$570 = 150 + 420v$

$v = +1.0\,\mathrm{m\,s^{-1}}$ [1]

The velocity v is positive; therefore the 420 kg car changes direction after the collision. [1]