1.6 Momentum

Name: _____ Class: _____ Date: _____ **Total: 32 marks**

0 Vocabulary

Word	Example
energy /'enədʒi/ 能量	Food gives your body the **energy** it needs to move. 食物为你的身体提供运动所需的**能量**。
momentum /məʊ'mentəm/ 动量	A heavy truck has a lot of **momentum**. 一辆很重的卡车具有很大的**动量**。
at rest /æt rest/ 静止	The particle is **at rest** when its velocity is zero. 当粒子的速度为零时，它处于**静止**状态。
equilibrium /ˌiːkwɪ'lɪbrɪəm/ 平衡	The book is in **equilibrium** because the forces balance. 书处于**平衡**状态，因为各个力相互平衡。
impulse /'ɪmpʌls/ 冲量	A kick gives the ball an **impulse**. 踢球给球一个**冲量**。
conservation of momentum 动量守恒 /ˌkɒnsə'veɪʃn ɒv məʊ'mentəm/	**Conservation of momentum** means the total momentum stays the same. **动量守恒**是指总动量保持不变。
kinetic /kɪ'netɪk/ 动能	A moving car has **kinetic** energy. 运动的汽车具有**动能**。
chemical /'kemɪkl/ 化学能	Food stores **chemical** energy. 食物储存着**化学能**。
elastic (strain) /ɪ'læstɪk/ 弹性势能	A stretched spring stores **elastic (strain)** energy. 被拉伸的弹簧储存着**弹性势能**。
internal (thermal) 内能 /ɪn'tɜːnl/	A hot drink has a lot of **internal (thermal)** energy. 一杯热饮具有大量**内能**。

1 Key knowledge and worked examples

Study these first. Each one shows the method for a question type used later: follow the steps and you can do the Practice and Exam-style questions yourself.

■ Momentum, impulse and force

quantity	equation	unit
momentum	$p = mv$	kg m/s
impulse	$F\Delta t = \Delta(mv)$	N s (the same as kg m/s)
resultant force	$F = \dfrac{\Delta p}{\Delta t}$	N

- Momentum is a **vector**: choose one direction as positive and give velocities the other way a minus sign.
- **Conservation of momentum:** when no external force acts, the total momentum before a collision or explosion equals the total momentum after.
- Spreading the same change in momentum over a **longer time** gives a **smaller force**: airbags, crumple zones, bending your knees on landing.

■ Worked example 1: a collision with both objects moving

Take right as positive. A 2.0 kg trolley moving at 3.0 $\dfrac{\text{m}}{\text{s}}$ to the right hits a 1.0 kg trolley moving at 1.0 $\dfrac{\text{m}}{\text{s}}$ to the left. They stick together. Find their velocity after.



1. No external force acts, so total momentum is conserved; the left-moving trolley has $u_2 = -1.0\ \dfrac{\text{m}}{\text{s}}$.
2. Momentum before, $p = m_1u_1 + m_2u_2$:

$$p = m_1u_1 + m_2u_2 = (2.0\text{ kg})(3.0\ \tfrac{\text{m}}{\text{s}}) + (1.0\text{ kg})(-1.0\ \tfrac{\text{m}}{\text{s}}) = 5.0\text{ kg m/s}$$

3. After, they move together: $(m_1 + m_2)v = p$, so $v = \dfrac{p}{m_1 + m_2}$.

$$v = \frac{p}{m_1 + m_2} = \frac{5.0\text{ kg m/s}}{3.0\text{ kg}} = \mathbf{1.7}\text{ m/s to the right}$$

■ Worked example 2: pushed apart from rest

Two skaters, of mass 60 kg and 40 kg, stand still and push apart. The 40 kg skater moves left at 1.5 $\dfrac{\text{m}}{\text{s}}$. Find the velocity of the 60 kg skater.

1. They start at rest, so the total momentum is zero before and must be zero after.

2. Momentum of the 40 kg skater: $p = mv = (40\text{ kg})(1.5\ \frac{\text{m}}{\text{s}}) = 60$ kg m/s to the left.
3. The other skater has equal momentum the other way, $mv = 60$ kg m/s, so $v = \frac{p}{m}$:

$$v = \frac{p}{m} = \frac{60\text{ kg m/s}}{60\text{ kg}} = \mathbf{1.0}\text{ m/s to the right}$$

■ **Worked example 3: the force in a rebound**

A 0.50 kg ball hits a wall at 8.0 $\frac{\text{m}}{\text{s}}$ and rebounds at 6.0 $\frac{\text{m}}{\text{s}}$. It touches the wall for 0.020 s. Find the average force on the ball.

1. Take the rebound direction as positive: $u = -8.0\ \frac{\text{m}}{\text{s}}$, $v = +6.0\ \frac{\text{m}}{\text{s}}$.
2. Change in momentum $\Delta p = mv - mu$:

$$\Delta p = mv - mu = (0.50\text{ kg})(6.0\ \tfrac{\text{m}}{\text{s}}) - (0.50\text{ kg})(-8.0\ \tfrac{\text{m}}{\text{s}}) = 7.0\text{ kg m/s}$$

3. Force is the rate of change of momentum, $F = \frac{\Delta p}{\Delta t}$:

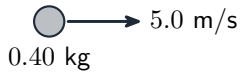
$$F = \frac{\Delta p}{\Delta t} = \frac{7.0\text{ kg m/s}}{0.020\text{ s}} = \mathbf{350}\text{ N}$$

■ **Watch out**

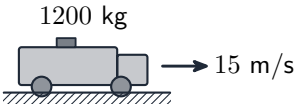
- In a rebound the speeds **add**: $\Delta p = m(v_1 + v_2)$, not $m(v_2 - v_1)$.
- Convert milliseconds: 9.7 ms $= 9.7 \times 10^{-3}$ s.

2 Practice

2.1 Find the momentum of a 0.40 kg ball moving at 5.0 $\frac{\text{m}}{\text{s}}$. [2]



2.2 A car of mass 1200 kg moves at 15 $\frac{\text{m}}{\text{s}}$. Find its momentum. [2]



exercises.lol exercises.com.cn

2.3 State the principle of conservation of momentum. [1]

conservation of momentum

2.4 State what is meant by impulse, and give its unit. [2]

impulse

2.5 The momentum of a lorry increases from 24 000 kg m/s to 36 000 kg m/s in 6.0 s. Calculate the resultant force on the lorry. [2]



24 000 → 36 000 kg m/s in 6.0 s

3 Exam-style questions

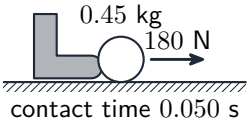
3.1 The momentum of an object is its mass multiplied by its: [1]

momentum

- ☐ **A** acceleration
- **B** velocity
- **C** weight
- **D** density

3.2 A ball of mass 0.45 kg is at rest. A player kicks it, and the boot is in contact with the ball for 0.050 s. The average force on the ball is 180 N. Which row gives the impulse on the ball and its average acceleration during the kick? [1]

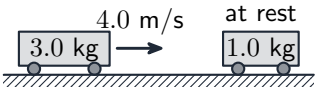
	impulse / N s	acceleration / m/s^2
A	9.0	20
B	9.0	400
C	3600	20
D	3600	400



exercises.lol exercises.com.cn

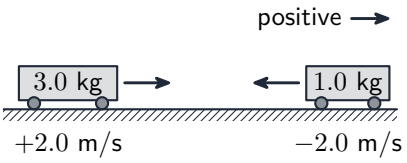
3.3 A 3.0 kg trolley moving at 4.0 $\frac{\text{m}}{\text{s}}$ collides with a stationary 1.0 kg trolley and they move off together.

(a) Calculate the total momentum before the collision. [2]



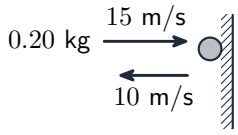
(b) Calculate their common velocity after the collision. [2]

3.4 Take right as positive. A 3.0 kg trolley moving at 2.0 $\frac{\text{m}}{\text{s}}$ to the right sticks to a 1.0 kg trolley moving at 2.0 $\frac{\text{m}}{\text{s}}$ to the left. No external force acts. Calculate the combined velocity, and explain why the directions must be kept. [4]



3.5 A ball of mass 0.20 kg hits a wall at 15 $\frac{\text{m}}{\text{s}}$ and rebounds along the same line at 10 $\frac{\text{m}}{\text{s}}$. It is in contact with the wall for 0.050 s.

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



(b) Calculate the average force exerted on the ball by the wall. [2]

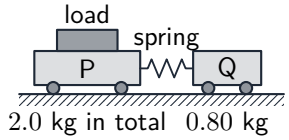
3.6 Explain how an airbag reduces the force on a driver in a crash. [2]



3.7 Two trolleys, P and Q, are held at rest on a frictionless horizontal track with a compressed spring between them. Trolley P, with its load, has a total mass of 2.0 kg. Trolley Q has a mass of 0.80 kg. When they are released, Q moves to the right at 0.50 $\frac{\text{m}}{\text{s}}$.

(a) State the total momentum of the two trolleys before they are released. [1]

(b) Calculate the velocity of trolley P after release. [3]



(c) Calculate the kinetic energy of trolley Q. [2]

(d) State the energy transfer that takes place as the spring expands. [1]

exercises.lol exercises.com.cn

Solutions

Each answer shows the steps, then the **result**.

2.1

- momentum is mass times velocity, $p = mv$

$$p = mv = (0.40\ \text{kg})(5.0\ \frac{\text{m}}{\text{s}}) = \mathbf{2.0}\ \text{kg m/s}$$

2.2

- $p = mv$

$$p = mv = (1200\ \text{kg})(15\ \frac{\text{m}}{\text{s}}) = \mathbf{18\,000}\ \text{kg m/s}$$

2.3

- when no external force acts, the total momentum before a collision equals the total momentum after

2.4

- impulse is force multiplied by the time for which it acts, $F\Delta t$, equal to the change in momentum
- unit: N s (or kg m/s)

2.5

- resultant force is the rate of change of momentum, $F = \dfrac{\Delta p}{\Delta t}$

$$F = \frac{\Delta p}{\Delta t} = \frac{36\,000\ \text{kg m/s} - 24\,000\ \text{kg m/s}}{6.0\ \text{s}} = \mathbf{2000}\ \text{N}$$

3.1 B

- $p = mv$, mass times velocity

3.2 B

- impulse $F\Delta t = (180\ \text{N})(0.050\ \text{s}) = 9.0\ \text{N s}$
- acceleration $a = \dfrac{F}{m} = \dfrac{180\ \text{N}}{0.45\ \text{kg}} = 400\ \dfrac{\text{m}}{\text{s}^2}$; 20 is the final speed in m/s, not the acceleration

3.3

(a)

- only the moving trolley has momentum: $p = mv$

$$p = mv = (3.0\ \text{kg})(4.0\ \frac{\text{m}}{\text{s}}) = \mathbf{12}\ \text{kg m/s}$$

exercises.lol exercises.com.cn

(b)

- momentum is conserved and they move together: $(m_1 + m_2)v = p$

$$v = \frac{p}{m_1 + m_2} = \frac{12 \text{ kg m/s}}{4.0 \text{ kg}} = \mathbf{3.0} \frac{\text{m}}{\text{s}}$$

3.4

- momentum before, with left negative: $p = m_1u_1 + m_2u_2$

$$p = (3.0 \text{ kg})(2.0 \frac{\text{m}}{\text{s}}) + (1.0 \text{ kg})(-2.0 \frac{\text{m}}{\text{s}}) = 4.0 \text{ kg m/s}$$

- conserved, moving together: $v = \frac{p}{m_1 + m_2}$

$$v = \frac{4.0 \text{ kg m/s}}{4.0 \text{ kg}} = \mathbf{1.0} \text{ m/s to the right}$$

- momentum is a vector: the trolleys move in opposite directions, so their momenta partly cancel; adding them as sizes would give 8.0 kg m/s and the wrong answer

3.5

(a)

- the speeds add because the direction reverses: $\Delta p = m(v_1 + v_2)$

$$\Delta p = m(v_1 + v_2) = (0.20 \text{ kg})(15 \frac{\text{m}}{\text{s}} + 10 \frac{\text{m}}{\text{s}}) = \mathbf{5.0} \text{ kg m/s}$$

(b)

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

$$F = \frac{\Delta p}{\Delta t} = \frac{5.0 \text{ kg m/s}}{0.050 \text{ s}} = \mathbf{100} \text{ N}$$

3.6

- the airbag increases the time taken for the driver's momentum to fall to zero
- the same change in momentum over a longer time means a smaller force, since $F = \frac{\Delta p}{\Delta t}$

3.7

(a)

- zero: both trolleys are at rest

(b)

- total momentum stays zero, so P's momentum equals Q's momentum in the opposite direction

$$p_Q = mv = (0.80 \text{ kg})(0.50 \frac{\text{m}}{\text{s}}) = 0.40 \text{ kg m/s}$$

- $v = \frac{p}{m}$ for P:

$$v = \frac{p}{m} = \frac{0.40 \text{ kg m/s}}{2.0 \text{ kg}} = \mathbf{0.20} \text{ m/s to the left}$$

exercises.lol exercises.com.cn

(c)

- kinetic energy $E_k = \frac{1}{2}mv^2$

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2}(0.80 \text{ kg})(0.50 \frac{\text{m}}{\text{s}})^2 = \mathbf{0.10} \text{ J}$$

(d)

- from the elastic (strain) energy store of the spring to the kinetic energy stores of the trolleys

exercises.lol exercises.com.cn