

1.3 Forces and Newton's laws

Name: _____ Class: _____ Date: _____

Total: 25 marks

KEY WORDS free-body diagram • centre of gravity • resultant force • terminal velocity
• normal contact force

Objective

Build the skills to answer WPH11 questions on **forces** and **Newton's laws of motion**: draw free-body diagrams, apply $\sum F = ma$ with several forces, identify third-law pairs, and explain terminal velocity. This sheet covers Unit 1 statements 8–12 (with core practical 1 on sheet 1.1).

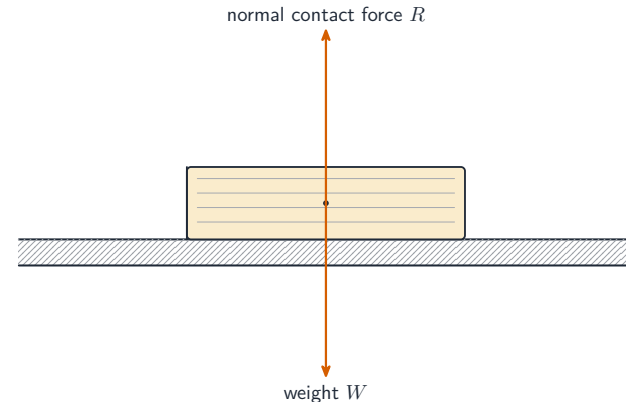
You must be able to:

- draw a free-body diagram with only the forces on the chosen object
- apply $\sum F = ma$, including zero resultant force (Newton's first law)
- use $g = \frac{F}{m}$ and $W = mg$
- state Newton's third law and test whether two forces form a third-law pair
- explain how a falling object reaches terminal velocity

1 Key knowledge and worked examples

■ Free-body diagrams

A free-body diagram shows **only the forces acting on the chosen object** – never the forces it exerts on other objects. On an extended body, the weight acts at the centre of gravity.



The book's weight W and the table's normal contact force R both act **on the book**, so they are **not** a Newton's-third-law pair – even though they are equal and opposite here. The third-law partner of the book's weight is the book's gravitational pull on the Earth.

■ Newton's three laws

1. **First law:** zero resultant force $\rightarrow$ no change in velocity (rest, or steady speed in a straight line). Balanced forces do not mean “not moving” – a car at constant velocity has balanced forces.
2. **Second law:** $\sum F = ma$. The resultant force sets the acceleration. List every force, choose a positive direction, add with signs, then apply.
3. **Third law:** if A exerts a force on B, then B exerts an equal, opposite force of the **same type** on A, along the same line – and the two forces act on **different bodies**.

Worked example (June 2025 Q11 style). A winch pulls a trailer with a resultant forward force of 4800 N, giving an acceleration of 0.31 m s^{-2} . Calculate the trailer's weight.

- Known: $\sum F$, a . Why: $\sum F = ma$ gives the mass; $W = mg$ converts mass to weight.

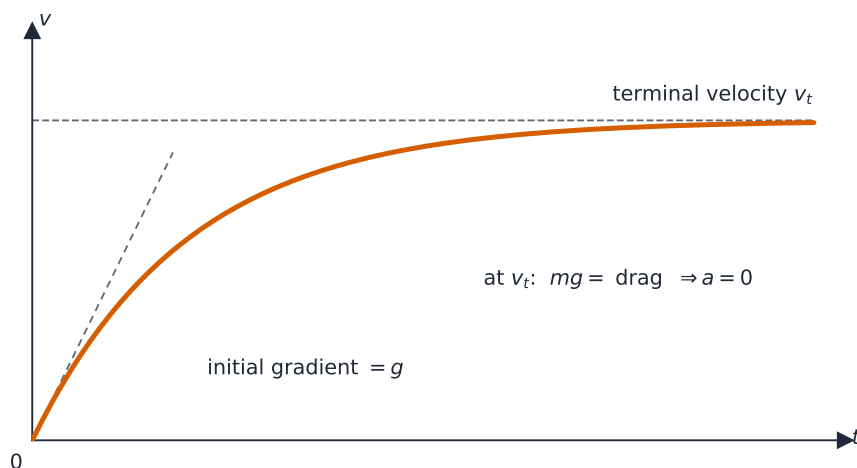
$$\sum F = ma \quad \Rightarrow \quad m = \frac{\sum F}{a} = \frac{4800 \text{ N}}{0.31 \text{ m s}^{-2}} = 15\,500 \text{ kg}$$

$$W = mg = 15\,500 \text{ kg} \times 9.81 \text{ N kg}^{-1} = 1.5 \times 10^5 \text{ N}$$

- Check: the answer is a force, so the unit is N, not kg – the mass-to-weight step is where marks are lost.

■ Terminal velocity

A falling object starts with acceleration g . As its speed grows, the drag force grows, so the resultant force and the acceleration fall. When drag (+ any upthrust) equals the weight, the resultant force is zero: the object falls at a constant **terminal velocity**.



- The **initial** gradient of the velocity–time graph is g ; the **final** gradient is zero.
- A heavier object of the same shape reaches a higher terminal velocity: it needs more drag to balance its weight, and drag needs more speed.
- When a parachute opens, drag suddenly exceeds weight: the resultant force is upwards, so the acceleration is upwards (the skydiver decelerates); as the speed falls, the drag falls, until drag = weight again at a new, lower terminal velocity.

2 Practice

2.1 A ball hangs from a string. (a) Draw the free-body diagram of the ball. (b) State the third-law partner of the string’s upward pull on the ball. [3]

2.2 A lift of mass 800 kg accelerates upwards at 1.2 m s^{-2} .

(a) Calculate the resultant force on the lift. [1]

(b) Calculate the tension in the cable. (*Hint: weight acts down, tension up.*) [3]

2.3 A book rests on a table. A student says: “The weight and the normal contact force are equal and opposite, so they are a Newton’s-third-law pair.” Explain the mistake. [2]

2.4 Two carts push apart on a frictionless track. Cart A pushes cart B to the right with 15 N. State the force on cart A: magnitude, direction, and which law you used. [2]

3 Exam-style questions

3.1 A person sits on a chair. The forces on the person are weight and the normal contact force from the chair. Why are these **not** a Newton’s-third-law pair? [1]

☐

- A the chair is stationary
- B the forces act in opposite directions
- C the forces act on the same object
- D the forces have the same magnitude

3.2 A coin and a feather are dropped together in air. Which statement is correct? [1]

☐

- A** the coin's initial acceleration is greater than the feather's
- B** the feather's initial acceleration is greater than the coin's
- C** their initial accelerations are equal, and they reach the same terminal velocity
- D** their initial accelerations are equal, and the coin reaches a greater terminal velocity

3.3 A skydiver jumps from an aeroplane and falls vertically.

(a) Explain why the skydiver's acceleration decreases as her speed increases. [2]

(b) She opens her parachute. Explain, in terms of the forces, why she decelerates at first and why the deceleration then decreases until she reaches a new terminal velocity. [4]

3.4 A crate of weight 950 N hangs from a helicopter by a cable. The helicopter rises so that the crate accelerates upwards at 0.80 m s^{-2} .

(a) Calculate the mass of the crate. [1]

(b) Calculate the tension in the cable. [3]

(c) The crate now descends at a **constant** velocity. State the tension in the cable, with a reason. [2]

Solutions

2.1 (a) Two arrows from the ball's centre: weight downwards, tension upwards, equal lengths. (b) The ball's downward pull on the string, equal and opposite, acting on the **string**.

2.2 (a) $\sum F = ma = 800 \text{ kg} \times 1.2 \text{ m s}^{-2} = 960 \text{ N}$. (b) Up positive: $T - W = ma$. $W = mg = 800 \text{ kg} \times 9.81 \text{ N kg}^{-1} = 7850 \text{ N}$, so $T = ma + mg = 960 \text{ N} + 7850 \text{ N} = 8800 \text{ N}$.

2.3 Both forces act on the **same body** (the book); a third-law pair acts on different bodies – the partners are the Earth's pull on the book / the book's pull on the Earth, and the table's push on the book / the book's push on the table.

2.4 15 N to the **left**, by Newton's third law – B pushes A back with an equal and opposite force.

3.1 C. A third-law pair acts on different objects; these two both act on the person. B and D describe properties a third-law pair also has; A is irrelevant.

3.2 D. At release the only force is weight, so both start with acceleration g . Drag grows with speed and balances the weight sooner for the light feather, so the coin's terminal velocity is greater. C fails on terminal velocity; A and B fail on the initial acceleration.

3.3 (a) Weight is constant but drag increases with speed, so the resultant force – and by $\sum F = ma$ the acceleration – decreases. (b) On opening, drag becomes greater than weight, so the resultant force is upwards and she decelerates. As her speed falls, the drag falls, so the resultant upwards force – and the deceleration – decreases, until drag equals weight again and the velocity is constant.

3.4 (a) $m = \frac{W}{g} = \frac{950 \text{ N}}{9.81 \text{ N kg}^{-1}} = 96.8 \text{ kg}$. (b) Up positive: $T - W = ma$. $T = ma + W = 96.8 \text{ kg} \times 0.80 \text{ m s}^{-2} + 950 \text{ N} = 77 \text{ N} + 950 \text{ N} = 1030 \text{ N}$. (c) $T = 950 \text{ N}$ – constant velocity means zero acceleration, so zero resultant force (Newton's first law).