5.1 Motion, Newton's laws and impulse

Name: _____ Class: _____ Date: _____ **Total: 30 marks**

KEY WORDS velocity • acceleration • ground reaction force • momentum • impulse • Newton's third law

Objective

Build the skills to answer exam questions on describing and explaining motion: velocity and acceleration, motion graphs, **Newton's laws** , momentum and **impulse** .

You must be able to:

- use distance, displacement, speed, velocity and acceleration with units
- read motion graphs: gradient and area
- apply Newton's three laws to sporting movements
- calculate momentum and impulse, and explain why longer contact times reduce force

1 Key knowledge and worked examples

Motion and Newton's laws

Scalars have size only (distance, speed, mass); **vectors** have size and direction (displacement, velocity, force).

$$v = \frac{\text{displacement}}{t} \qquad a = \frac{\Delta v}{t} \qquad p = mv \qquad \text{impulse} = F\,\Delta t = \Delta p$$

Graphs: on a displacement–time graph, the **gradient** is velocity. On a velocity–time graph, the gradient is **acceleration** and the **area** under the line is **displacement**. On a force–time graph, the area is **impulse**.

law	statement	sport example
first (inertia)	a body stays at rest or moves at constant velocity unless a resultant force acts	a ball keeps rolling until friction slows it
second	$F = ma$: resultant force = mass × acceleration	a bigger push gives a bigger acceleration
third	every action force has an equal and opposite reaction force	the sprinter pushes back on the blocks; the blocks push the sprinter forward (**ground reaction force**)

Impulse: the same change in momentum can come from a large force for a short time or a smaller force for a longer time. Bending the knees on landing or "giving" with the hands when catching makes the contact time longer, so the force is smaller and injury risk lower.

AHL: in running each foot contact gives a **braking** impulse then a **propulsive** impulse; the runner speeds up when the propulsive impulse is larger. From a jump's net impulse, take-off velocity $v = \text{impulse} \div m$, and height $h = v^2 \div 2g$ with $g = 9.81$ m s^{-2}.

Answer shapes: formula → substitute with units → answer with units and direction if it is a vector.

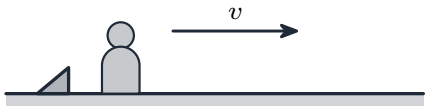
2 Practice

2.1 Distinguish between speed and velocity. [2]

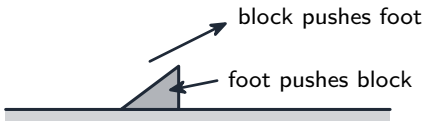


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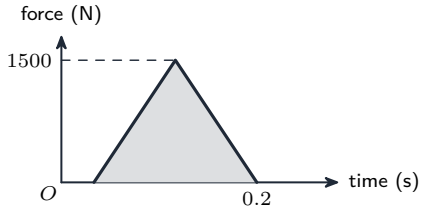
2.2 A 70 kg sprinter goes from rest to 10 m s^{-1} in 2.5 s. Calculate her mean acceleration and the mean resultant force on her. [3]



2.3 Use Newton's third law to explain how a sprinter is pushed forward out of the blocks. [3]



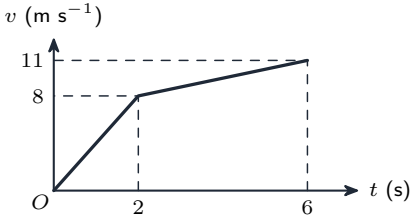
2.4 The force–time graph shows a push-off lasting 0.2 s. The force rises from 0 to 1500 N and falls back to 0 in a triangle shape. The athlete has a mass of 75 kg. Calculate the impulse and the change in velocity. [3]



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3 Exam-style questions

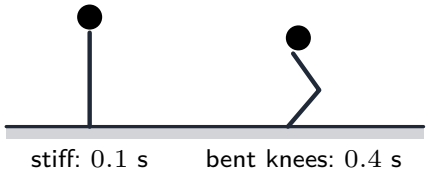
3.1 The velocity–time graph shows the first 6 s of a 100 m race.



(a) Describe the motion of the sprinter. [2]

(b) Calculate the displacement in the first 2 s. [2]

3.2 A 40 kg gymnast lands at 5 m s^{-1}. With stiff legs she stops in 0.1 s; with bent knees she stops in 0.4 s.

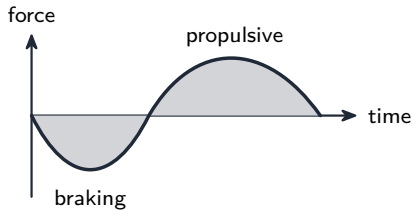


(a) Calculate her momentum just before landing. [1]

(b) Calculate the mean stopping force in each landing (ignore her weight). [3]

(c) Explain why bending the knees reduces the risk of injury. [2]

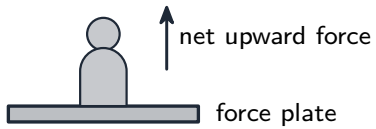
3.3 The graph shows the horizontal ground reaction force during one foot contact in running.



(a) Explain why the first part of the contact slows the runner. [2]

(b) Explain how the runner can speed up over several steps. [2]

3.4 In a vertical jump on a force plate, the net upward impulse is 180 N s. The jumper's mass is 60 kg.



(a) Calculate the take-off velocity. [2]

(b) Calculate the jump height ($g = 9.81$ m s^{-2}). [2]

(c) Suggest **one** reason why a jump-and-reach test may give a different height. [1]

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Solutions

Marking: **M1** a correct method, **A1** the correct answer, **B1** an independent mark.

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

2.1

speed is a scalar: distance per unit time, with no direction; velocity is a vector: displacement per unit time, with a direction

2.2

$a = 10 \div 2.5 = \mathbf{4}$ m s^{-2}; $F = ma = 70 \times 4 = \mathbf{280}$ N

2.3

the sprinter pushes backwards (and down) on the blocks with her legs (action); the blocks push on her with an equal force in the opposite direction (reaction); this forward reaction force accelerates her forward (ground reaction force)

2.4

impulse $= \frac{1}{2} \times 1500 \times 0.2 = \mathbf{150}$ N s; $\Delta v = 150 \div 75 = \mathbf{2}$ m s^{-1}

3.1

(a) large acceleration in the first 2 s; then a smaller acceleration up to about 11 m s^{-1}

(b) area of triangle $= \frac{1}{2} \times 2 \times 8 = \mathbf{8}$ m

3.2

(a) $p = 40 \times 5 = \mathbf{200}$ kg m s^{-1}

(b) $F = \Delta p \div \Delta t$; stiff: $200 \div 0.1 = \mathbf{2000}$ N; bent: $200 \div 0.4 = \mathbf{500}$ N

(c) the same change in momentum (impulse) happens over a longer time; so the force on bones, joints and ligaments is smaller

3.3

(a) the foot lands ahead of the body, so the ground pushes backwards on the runner; this braking impulse reduces forward momentum

(b) the propulsive impulse must be larger than the braking impulse; so the net impulse is forward and momentum (velocity) rises with each step

3.4

(a) $v = 180 \div 60 = \mathbf{3.0}$ m s^{-1}

(b) $h = v^2 \div 2g = 9 \div 19.62 \approx \mathbf{0.46}$ m

(c) e.g. arm reach and shoulder movement add height; the reach is measured at the top of the hand, not the centre of mass; timing error

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