5.1 Motion, Newton's laws and impulse

Name: _____ Class: _____ Date: _____ **Total: 18 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).

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

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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**.

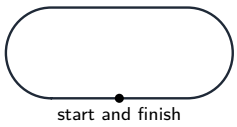
law	statement	sport example
first (inertia)	a body stays at rest or moves at constant velocity unless a resultant force acts	a ball keeps rolling until friction slows it
second	$F = ma$: resultant force = mass × acceleration	a bigger push gives a bigger acceleration
third	every action force has an equal 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.

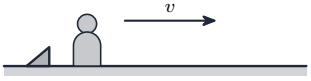
Answer shapes: formula → substitute with units → answer with units and direction if it is a vector.

2 Practice

2.1 Distinguish between speed and velocity. [2]

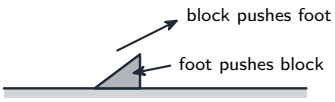


2.2 A 70 kg sprinter goes from rest to 10 m s^{-1} in 2.5 s. Calculate her mean acceleration and the mean resultant force on her. [3]



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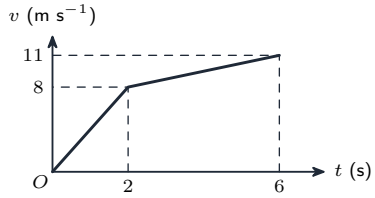
2.3 Use Newton's third law to explain how a sprinter is pushed forward out of the blocks. [3]



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]

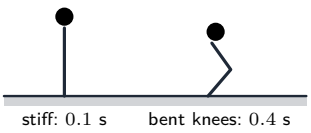


(b) Calculate the displacement in the first 2 s. [2]

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]

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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)

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