Topic 1 Mechanics
1C Momentum

1C.1 Momentum

1 (a) 240 kg m s^{-1}

(b) 588 kg m s^{-1}

(c) 2.5×10^{-4} kg m s^{-1}

2 Motorcyclist: estimate mass as 80 kg and speed as 30 m s^{-1}, so p = 2400 kg m s^{-1}

Skateboarder: estimate mass as 65 kg and speed as 4 m s^{-1}, so p = 260 kg m s^{-1}

3 Larger forces cause greater injuries. Force required is proportional to rate of change of momentum (Newton's second law).

The airbag removes momentum in a greater time than the dashboard, so the rate of change of momentum is lower, so the force needed is lower, resulting in less injuries.

4 Students' own answers, using $F = \frac{\Delta p}{t}$:

e.g. a Frisbee's estimated throw speed is 5 m s^{-1} (initially at rest); estimated mass is 100 g; estimated time for which hand applies force to throw is 0.1 s:

$F = \frac{\Delta p}{t} = \frac{0.1 \times 5}{0.1} = 5$ N

1C.2 Conservation of linear momentum

1 0.15 m s^{-1}

2 (a) 0.2 m s^{-1}

(b) 100 N

3 The force that pushes the boy forwards from the boat has an equal and opposite reaction force pushing the boat away, so it is likely that the boat will move out from under him without providing enough forward force to make him reach the jetty before he falls into the water.

4 (a) Longer arrow labelled '1200 kg m s^{-1}' at 80° to shorter arrow labelled '600 kg m s^{-1}'. Either drawn as parallelogram rule, or one after the other, with resultant momentum vector arrow drawn in. Resultant is 1430 kg m s^{-1} at an angle of 56° to the river current (600 kg m s^{-1} vector).

(b) Resulting velocity = 4.77 m s^{-1} at 56° to current, so 2.67 m s^{-1} along current direction and 3.94 m s^{-1} towards riverbank. Time to reach waterfall = 37 s. Time to reach bank = 4.1 s, so they reach the bank safely.

1C Exam practice

1 C

2 B

3 A

4 B

5 A

6 QWC (quality of written communication) – spelling of technical terms must be correct and the answer must be organised in a logical sequence:

Momentum conservation

Total/initial momentum = 0

Momentum of slime equal momentum of bacteria, which moves in opposite direction

OR

Force on slime, so equal and opposite force on bacteria. Thus cause the rate of change of momentum $\frac{\Delta mv}{t}$ to bacteria, which moves in opposite direction.

7 (a) QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate. Include the following:

Measurement of appropriate quantity, e.g. height/distance/time

Calculate the speed or inferred by an equation

Speed on impact

Statement of how method shows momentum has been conserved

(b) Collisions inelastic / KE is transferred in collisions to internal energy / thermal energy / to KE of middle balls / to sound

Eventually stops because all energy is transferred

8 (a) The weight of the hanging masses will be transferred as tension in the string to become a resultant force on the trolley. Newton's second law tells us that this will lead to an acceleration equal to $\frac{W}{m}$ (W = weight of hanging masses; m = mass of trolley and hanging masses combined). This acceleration causes a change in velocity which means a change in momentum.

(b) Mass of trolley = $\frac{2.85}{9.81}$ = 0.291 kg

Total mass = 0.350 + 0.291 = 0.641 kg

$a = \frac{F}{m} = \frac{2.85}{0.641}$ = 4.45 m s^{-2}

(c) $p = mv$ = 0.35 × 11.1 = 3.89 kg m s^{-1}

(d) The total momentum of all objects involved in a collision, accounting for the vector nature of momentum, will be the same before and after the collision.

(e) Initially, all the momentum of the system is carried by the moving trolley.

When this stops it loses all its momentum.

In order for momentum to be conserved, the second trolley must leave the collision with the amount of momentum that the first one had initially.

As the trolleys are identical, the second trolley will leave at the same speed that the first one came in with.

(f) Initially, all the momentum of the system is carried by the moving trolley.

In order for momentum to be conserved, the combined pair of trolleys must leave the collision with the amount of momentum that the first one had initially.

As the trolleys are identical, the total mass will be double that of the incoming trolley.

So they will leave at half the same speed that the first one came in with.

(g) Tie the two trolleys together, with a compressed spring, or repelling magnets, between them.

With the combination stationary, burn through the tie so that they fly apart in an explosion.

Have light gates to monitor speed of each trolley on either side of the explosion.

9 Award 1 mark for the (QWC) quality of written communication.

Award a maximum of 5 marks from the following expected answer points:

When objects collide, there is a Newton's third law force pair between

for the duration of the collision

Which means equal and opposite forces act on each object

for the same length of time

The change in the momentum of an object (impulse) is equal to $F \times t$

Each object experiences equal change in momentum (impulse)

but in opposite directions

The total change in momentum is the sum of the individual changes in momentum

so the total change in momentum is zero / momentum is conserved

10 (a) Momentum is initially constant at 0.8 kg m s (towards the goalkeeper) for the first 4 ms.

Over the period 4–8 ms, it changes uniformly by −0.5 kg m s^{-1} per millisecond.

Momentum is then constant at −1.2 kg m s^{-1} away from the goalkeeper for the remaining 2 ms.

(b) The leg pads provide a resultant force on the ball, which will change the momentum according to Newton's second law.

(c) (i) 0 (zero) newtons

(ii) 500 N

(iii) (zero) newtons

(d) Graph with the following points:

First horizontal line at 0.4 kg m s^{-1}, then momentum changes between 4–6 ms

Final horizontal line is at a momentum of −0.6 kg m s^{-1}