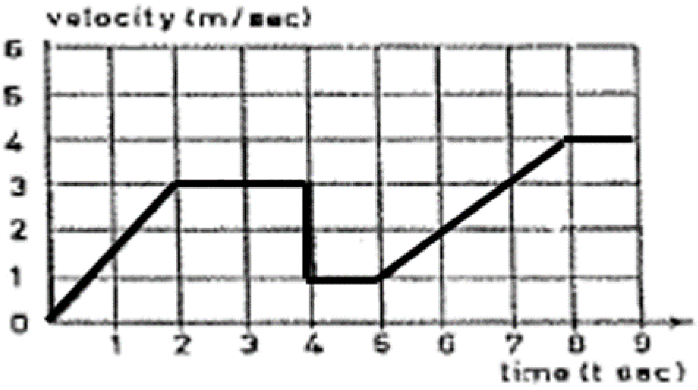
Momentum and impulse



The above graph represents a plot of velocity against time of a cart of initial mass 1 kg as it travels in a straight line across a level surface. At some instant during the 9 seconds, an additional mass was dropped vertically on to the cart.

1967 Question 15, 1 mark 96%

At what time did this occur?

There is a drop in velocity at 4 s due to a sudden increase in mass.

$\therefore$ ***4 s (ANS)***

1967 Question 16, 1 mark 67%

What was the value (in kg) of the additional mass dropped vertically on to the cart?

From conservation of momentum

$\therefore 1 \times 3 = m \times 1$

$\therefore m = 3$

$\therefore$ *the mass increased from 1 to 3 kg*

$\therefore$ ***2 kg (ANS)***

A meteor assumed to be of constant mass 1 kg, moving with a speed 12,000 m s^{-1}, is travelling vertically down towards a planet. The planet's dense atmosphere slows it down to 10,000 m s^{-1} in 4 secs.

1969 Question 10, 2 marks (modified) 61%

At the end of this 4 seconds when the meteor has slowed to 10,000 m s^{-1}, the meteor strikes a space vehicle of mass 200 kg which is moving horizontally at a speed of 10,000 m s^{-1}. The collision takes place in such a way that the meteor lodges in the space vehicle. What is the tangent of the angle θ to the horizontal with which the vehicle continues its course immediately after the collision and what is its speed?

Use conservation of momentum to find the final direction.

Vertical momentum $= 1 \times 10\,000$

$= 1.0 \times 10^4$

Horizontal momentum $= 200 \times 10\,000$

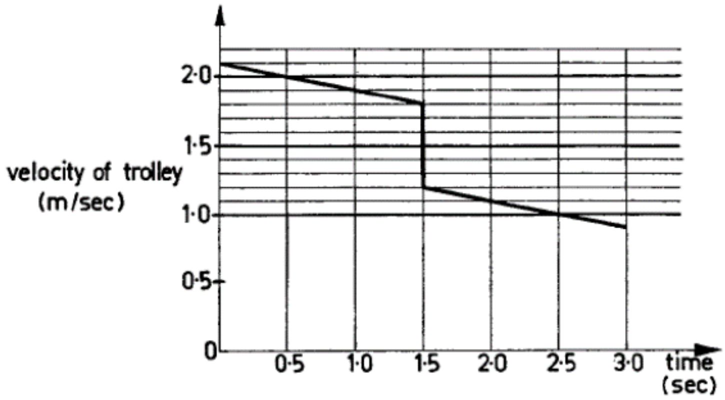
$= 2.0 \times 10^6$

$$\therefore \tan\theta = \frac{1.0 \times 10^4}{2.0 \times 10^6}$$

$\therefore$ $\boldsymbol{\tan\theta = 5.0 \times 10^{-3}}$ ***(ANS)***

Momentum and impulse

A trolley of mass 6.0 kilogram is given a push and then allowed to roll freely along a table. Its velocity is measured continuously. At time 1.5 second a lump of clay is dropped vertically onto the trolley



1970 Question 14, 1 mark 58%

What was the mass of the lump of clay which was dropped onto the trolley?

Momentum will be conserved.

$\therefore p_i = p_f$

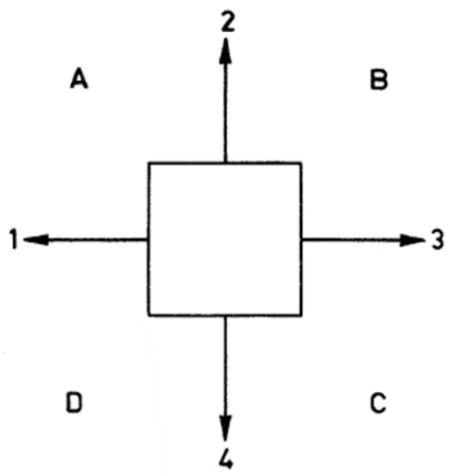
$p_i = 6.0 \times 1.8$ *(from graph)*

$p_f = (6.0 + M) \times 1.2$ *(from graph)*

$\therefore 10.8 = 7.2 + 1.2M$

$\therefore 3.6 = 1.2M$

$\therefore \mathbf{M = 3.0\ kg}$ ***(ANS)***



A sled resting on a smooth horizontal ice surface is equipped with four identical fixed catapults. Each catapult throws a 1.0 kg projectile horizontally at a speed of 100 m s^{-1} relative to the sled. The total mass of the sled and projectiles before firing is 10 kg.

The catapults are fired in order 1, 2, 3, 4 in the directions shown.

1971 Question 7, 1 mark 78%

What is the speed of the sled relative to the ice after the first catapult is fired?

Use conservation of momentum. $\therefore p_{projectile} + p_{sled} = 0$

$\therefore 1 \times 100 = (10 - 1) \times v_{sled}$

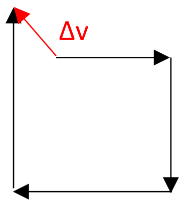
$\therefore \mathbf{v_{sled} = 11.1\ m\ s^{-1}}$ ***(ANS)***

Momentum and impulse

1971 Question 8, 1 mark 39%

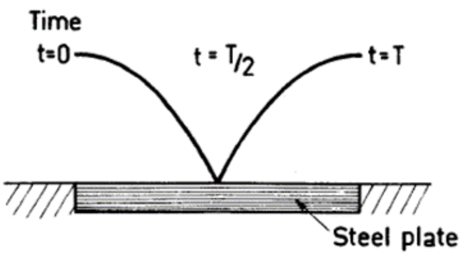
State the quadrant (A, B, C or D) into which the final velocity of the sled is directed after all the catapults are fired, if the final velocity is zero give E as your answer.

After the first catapult is fired, the sled will move in the direction ‘3’. After the second catapult is fired the sled will now have a velocity in the direction ‘3’ plus a larger velocity in direction ‘4’. The second velocity will be larger since the remaining mass of the sled is less.
After firing catapult 3, the sled will have a third component to its velocity in the direction ‘1’.
After firing catapult 4, the sled will have a fourth component to its velocity in the direction ‘2’.
The vector sum of the velocities is shown as



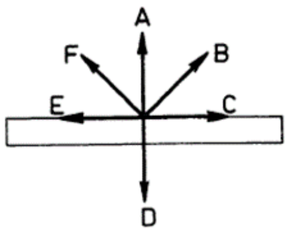
∴ **A (ANS)**

A steel ball is projected horizontally and makes a perfectly elastic collision with a steel plate embedded in the ground.

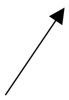


1971 Question 38, 1 mark 70%

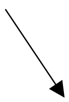
Which arrow (A - F) best describes the direction of the impulse of the plate on the ball?



Just after the collision the momentum is tangential to the path.

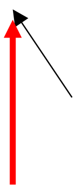
∴ p_f = 

Just before the collision the momentum is tangential to the path.

∴ p_i = 

The change in momentum = Impulse

∴ $I = p_f - p_i$



∴ I =

∴ A (ANS)

1971 Question 39, 1 mark 19%

Which one or more of the following statements about the momentum of the ball are true?

A. The horizontal component of the momentum of the ball remains constant throughout the time interval $0 \le t \le T$

B. The vertical component of the momentum just before $t = \frac{T}{2}$ is equal to the vertical component just after $t = \frac{T}{2}$ because the collision is elastic.

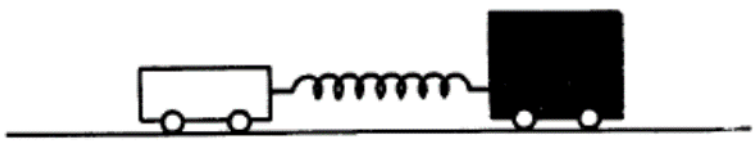
C. The total momentum of the ball remains constant throughout the time interval $0 \le t \le T$, but the horizontal component is partly changed into a vertical component due to the action of the gravitational field.

D. During the impact there is a transfer of momentum to the earth.

(one or more answers)

As the collision is elastic, the final KE is equal to the initial KE, therefore the final velocity has the same magnitude as the initial. Hence the magnitude of the final momentum is the same as the magnitude of the initial momentum.
For this to be true, the horizontal component of the momentum must be constant, and the vertical component will have the same magnitude but be in the opposite direction.
For this to occur, the initial vertical momentum must be transferred to the ground, and then the ground must transfer momentum in the opposite direction.

A & D (ANS)



A light spring is permanently connected between two trolleys of masses, 1.0 kg and 4.0 kg which can move along a straight horizontal track. The spring is compressed and then the trolleys are released simultaneously from rest.

1971 Question 40, 1 mark 92%

What is the speed of the lighter trolley when the speed of the heavier trolley is 2 m sec^{-1}?

Before the trolleys are released the momentum is zero.
Momentum is conserved so the final momentum = 0
The heavier trolley has a momentum of
$4 \times 2 = 8$ N s (to the right)
The lighter trolley must have the same momentum, only it will be to the left.

$\therefore 8 = m \times v$

$\therefore 8 = 1 \times v$

$\therefore \boldsymbol{v = 8\ m\ s^{-1}}$ ***(ANS)***

1971 Question 42, 1 mark 59%

When the heavier trolley first comes momentarily to rest, the velocity of the lighter trolley is

A. zero.

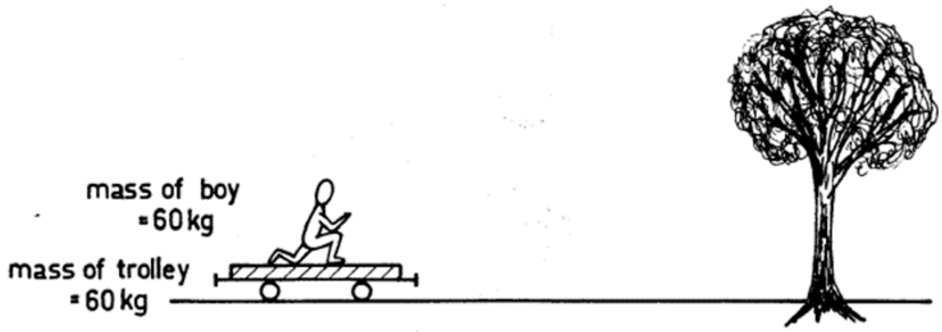
B. in the same direction as its initial velocity.

C. in the opposite direction to its initial velocity.

D. indeterminate - there is not enough information given.

Momentum is always conserved. If the heavier trolley has zero momentum, so must the lighter trolley.
$\therefore$ ***A (ANS)***

A boy of mass 60 kg rides on a 60 kg trolley moving with constant speed of 5 m s^{-1} along a horizontal track. Frictional forces can be neglected. The boy jumps vertically with respect to the moving trolley to grab the overhanging branch of a tree.



1972 Question 23, 1 mark 50%

What is the speed of the trolley after the boy has jumped off?

The boy will transfer his momentum to the earth, via the tree. The momentum of the trolley will not change, therefore the speed of the trolley will remain constant.
$\therefore$ ***5.0 m s^{-1} (ANS)***

A trolley of mass 100 kg moving with velocity 6.0 m s^{-1} collides with a stationary trolley of mass 50 kg, and becomes coupled to it.

1972 Question 37, 1 mark 67%

How much kinetic energy is lost in the collision?

Use conservation of momentum to find the final speed.

$\therefore p_f = p_i$

$\therefore (100 + 50) \times v_f = 100 \times 6$

$\therefore v_f = 4.0\ m\ s^{-1}$

$KE_{final} = \frac{1}{2} mv^2$

$= \frac{1}{2} \times 150 \times 4.0^2$

$= 1200\ J$

$KE_{initial} = \frac{1}{2} mv^2$

$= \frac{1}{2} \times 100 \times 6.0^2 = 1800\ J$ $\therefore$ ***600 J is lost (ANS)***

Momentum and impulse

1972 Question 39, 1 mark 77%

The area under the graph of **net force** versus **time** for an object represents

A change in potential energy

B acceleration

C work done

D power

E change in momentum

By definition, the area under the net force-time graph is the change in momentum, or the impulse.

$\therefore$ ***E (ANS)***

The following data were obtained from a multi-flash photograph of a golf club hitting a stationary ball.

Speed of club head just before impact 50 m s^{-1}

Speed of club head just after impact 32 m s^{-1}

The mass of the golf ball is 0.050 kg.

The effective mass of the golf club (which may be assumed to be concentrated in the head) is 0.20 kg.

Include units in answers to questions 28, 29, and 31.

1973 Question 28, 1 mark 47%

What is the impulse on the ball?

The impulse on the ball is equal and opposite to the impulse on the club head.
The impulse on the club head is given by its change in momentum.

$\therefore I = p_f - p_i$

$\therefore I = 0.20 \times 32 - 0.20 \times 50$

$\therefore I = -3.6$

$\therefore$ ***I = 3.6 N s (ANS)***

1973 Question 29, 1 mark 70%

The club and ball are in contact for 0.010s. What is the average force exerted on the ball?

Use $I = F\Delta t$

$\therefore 3.6 = F \times 0.010$

$\therefore$ ***F = 360 N (ANS)***

1973 Question 30, 1 mark 58%

What is the initial velocity of the ball?

This question wants the initial speed of the ball after being hit with the club head (It will slow down due to air resistance as it travels through the air).

Use $I = m\Delta v$

$\therefore 3.6 = 0.050 \times \Delta v$

$\therefore$ ***Δv = 72 m s^{-1} (ANS)***

Momentum and impulse

1973 Question 31, 1 mark 25%

How much kinetic energy is lost in the impact?

The KE lost in the impact is given by the difference between the KE lost by the club head and the KE gained by the ball.
The KE lost by the club head is given by $KE_f - KE_i$

$\therefore KE_{final} = \frac{1}{2} \times 0.20 \times 32^2$

$\therefore KE_{initial} = \frac{1}{2} \times 0.20 \times 50^2$

$\therefore \Delta KE = 102.4 - 250$

$\therefore \Delta KE_{club\ head} = -147.6$

The KE gained by the ball $= \frac{1}{2} \times 0.050 \times 72^2$

$\Delta KE_{ball} = 129.6$

$\therefore$ *KE lost in impact* $= 129.6 - 147.6$

= 18 J (ANS)

A sphere of mass 3 kg travelling North at 2 m s^{-1} collides with another sphere of mass 4 kg travelling East at

2 m s^{-1}.

1975 Question 8, 1 mark 67%

The magnitude of their resultant momentum after collision will be:

A zero

B 2 kg m s^{-1}

C 10 kg m s^{-1}

D 14 kg m s^{-1}

E dependent on whether the collision was elastic or inelastic

Momentum is a vector, therefore the direction needs to be considered.
From conservation of momentum, the final momentum will be the same as the initial momentum.
$\therefore p_i = 3.0 \times 2.0$ *(North)* $+ 4.0 \times 2$ *(East)*
$\therefore p_i = 10$ *kg m* s^{-1} *in a direction between North and East. (This is a 6:8:10 triangle)*

∴ C (ANS)

1975 Question 9, 1 mark 70%

The total kinetic energy of the two spheres after collision will be:

A 10 J

B 14 J

C 20 J

D 28 J

E dependent on whether the collision was elastic or inelastic

The total energy of the spheres cannot be calculated after the collision because it is not clear if the collision is elastic or not. If the collision was elastic, then the $KE_{final} = KE_{initial}$*, which can be calculated. If the collision is inelastic, then more information is required to calculate the final KE.*

∴ E (ANS)

Momentum and impulse

An object of mass 4.0 kg, has an initial velocity of 2.0 m s^{-1} north and a final velocity of 3.0 m s^{-1} south.

1976 Question 12, 1 mark 63%

What is the magnitude of the change in momentum?

Change in momentum is ALWAYS given by final – initial.
In this case final momentum is 4.0 × 3.0 (south), and the initial momentum is 4.0 × 2.0 (north).
∴ change in momentum is 12 (south) – 8 (north)
∴ change in momentum is 12 - - 8 (south)
∴ the magnitude of the change in momentum is
20 kg m s^{-1}.(ANS)

Various physical quantities can often be calculated from the area under graphs relating two physical quantities. For example, displacement can be found by calculating the area under a velocity versus time graph.

1976 Question 18, 1 mark 80%

The area under a graph of net force versus time for an object represents

A. change in Potential energy.

B. acceleration.

C. work done.

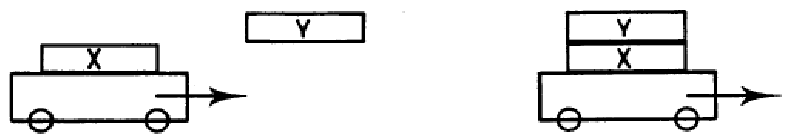
D. power.

E. change in momentum.

From definition
∴ E (ANS)

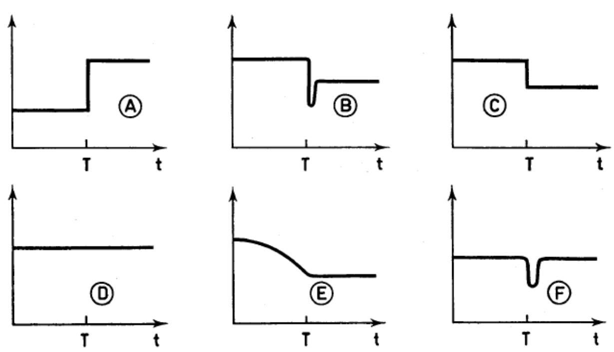
In an experiment, a laboratory cart carrying one brick is travelling at constant speed along a smooth level bench. Another identical brick is dropped at time T on to the cart.

The mass of the cart is equal to the mass of 1.5 bricks.



1976 Question 21, 1 mark 86%

Which of the graphs (A - F) below best represents the velocity of the cart as a function of time?



*The velocity of the cart will decrease at time T. From conservation of momentum principles, if the mass increases then the velocity must decrease. ∴ **C (ANS)***

Momentum and impulse

1976 Question 23, 1 mark 58%

Which of the graphs (**A - F**) above best represents the momentum of brick X?

This question is really asking what is the velocity of brick X?
The velocity of Brick X will decrease when brick Y drops onto it. Since momentum is conserved, initially brick Y hasn't any horizontal momentum, so what it gains must be lost from the initial cart-brick combination.
Block Y's vertical momentum is transferred to the earth. $\therefore$ ***C (ANS)***

1976 Question 24, 1 mark 37%

Which of the graphs (**A - F**) above best represents the total energy of cart and bricks?

The energy of the system does not change during the collision as there are no forces acting that will do work to change the motion $\therefore$ ***D (ANS)***

1976 Question 25, 1 mark 64%

In a second experiment, the same cart carries three identical bricks and is travelling at a constant speed of 1.1 ms^{-1}. A fourth brick is dropped on to the cart. What will the speed of the cart now be?

Momentum is conserved

$\therefore p_i = p_f$

$p_i = (3 + 1.5)m \times 1.1$

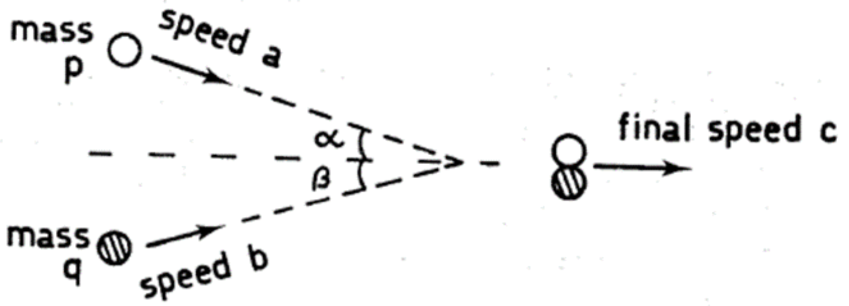
$= 4.95\ m$

$p_f = (4 + 1.5)\ m \times v_f$

$\therefore 5.5\ mv_f = 4.95\ m$

$\therefore v_f = \dfrac{4.95}{5.5}$

$\therefore \mathbf{v_f = 0.9\ m\ s^{-1}}$ ***(ANS)***



Two masses p and q collide, stick together, and move off as shown in the figure.

1977 Question 25, 1 mark 19%

Which *two* of the following equations correctly describe the motions of these masses?

A. $pa + qb = (p + q)c$.

B. $pa^2 + qb^2 = (p + q)c^2$.

C. $pa \cos\alpha + qb \cos\beta = (p + q)c$.

D. $pa^2 \cos^2\alpha + qb' \cos^2 \beta = (p + q)\ c^2$.

E. $pa \sin\alpha + qb \sin\beta = (p + q)c$.

F. $pa \sin\alpha - qb \sin\beta = 0$.

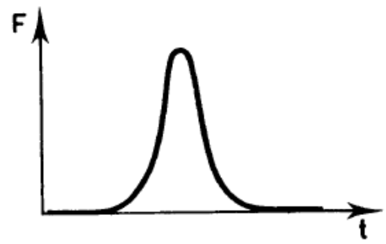
G. $pa^2 \sin^2\alpha - qb^2 \sin^2\beta = 0$.

From resolution of the vectors, the components in the horizontal direction must add to give the final momentum, whilst the components in the vertical direction cancel each other out.

$\therefore pa \cos\alpha + qb \cos\beta = (p + q)c$ *and* $pa \sin\alpha - qb \sin\beta = 0$ $\therefore$ ***C, F (ANS)***

Momentum and impulse

A cricket ball, travelling horizontally, is hit by a batsman so that it quickly returns to the bowler. The graph represents the variation of the force of the bat on the ball with time.



1978 Question 9, 1 mark 60%

The area under this graph represents:

A. The impulse of the bat on the ball

B. The change in kinetic energy of the ball

C. The change in momentum of the ball

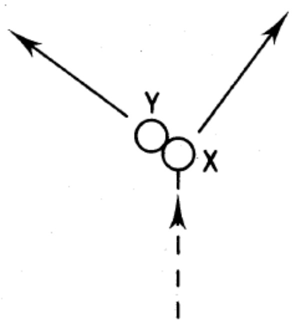
D. The average force on the ball during the time of contact

E. The work done on the ball.

(one or more answers)

By definition the area under the F vs t graph is the Impulse (or change in momentum)
∴ A C (ANS)

During a game of billiards, ball X strikes the stationary ball Y so that X and Y follow the paths shown.



1978 Question 22, 1 mark 67%

Which of the following statements about the momentum of ball X is correct?

A. Neither the magnitude nor the direction of the momentum has changed.

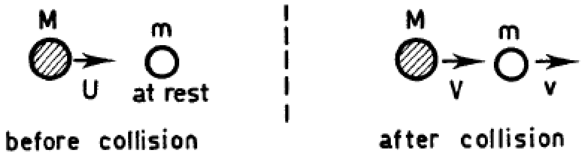
B. Only the direction of the momentum has changed.

C. The magnitude of the momentum has increased.

D. The magnitude of the momentum has decreased.

Ball Y will gain momentum, therefore ball X will lose that amount of momentum.
∴ D (ANS)

Momentum and impulse



A ball of mass M strikes a stationary ball of mass m elastically, and head-on.

1979 Question 24, 1 mark 66%

Which two of the following equations are correct?

A. $U = v + V$

B. $MU^2 = mv^2 + MV^2$

C. $M^2U^2 = m^2v^2 + M^2+V^2$

D. $MU = (m + M)(v + V)$

E. $MU = mv + MV$.

(one or more answers)

Momentum is always conserved, and so is energy as the collision is elastic.
$\therefore$ ***B, E (ANS)***

1979 Question 25, 1 mark 51%

If the balls are of equal mass, i.e. $\frac{M}{m} = 1$, then,

A. $V = \frac{1}{2}U$ and $v = \frac{1}{2}U$

B. $V = 0$ and $v = U$

C. $V = U$ and $v = 0$

D. $V = -U$ and $v = 2U$

E. $V = -½U$ and $v = ½U$

If the mass of both balls is the same, then this acts as Newton's cradle.
Therefore the initial ball will come to a stop and the second ball will move with the same speed as the initial ball. $\therefore$ ***B (ANS)***

Momentum and impulse

1979 Question 26, 1 mark 22%

If the balls are of unequal mass, then the ratio $\frac{V}{v}$ is equal to

A. $\frac{M-m}{2M}$

B. $\frac{M-m}{2m}$

C. $\frac{m}{M}$

D. $\frac{M}{M-m}$

E. $\frac{m}{M+m}$

This involves a fair bit of algebra. You need to use
$MU = mv + MV$ (1)
and $MU^2 = mv^2 + MV^2$ (2)
Square (1)
$M^2U^2 = m^2v^2 + 2mvMV + M^2V^2$ (3)
Multiply (2) by M
$M^2U^2 = Mmv^2 + M^2V^2$ (4)
Equate (3) and (4)
$m^2v^2 + 2mvMV + M^2V^2 = Mmv^2 + M^2V^2$
$\therefore m^2v^2 + 2mvMV = Mmv^2$
Divide b.s. by mv
$\therefore mv + 2MV = Mv$
$\therefore 2MV = (M - m)v$
$\therefore \frac{V}{v} = \frac{(M-m)}{2M}$

$\therefore$ A (ANS)

1979 Question 27, 1 mark 66%

If, instead of colliding elastically, the two masses had stuck together and moved off with velocity W, which of the following statements would be correct?

A. $MU = (M + m)W$.

B. $\frac{1}{2} MU^2 = \frac{1}{2} (M + m)W^2$

C. $M^2U^2 = M^2W^2 + m^2W^2$.

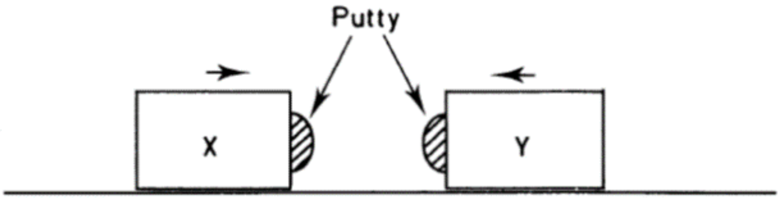
D. More than one of the above equations are correct.

E. None of the above equations is correct.

Momentum will be conserved. The final velocity is W. Therefore the final momentum is (M + m)W

$\therefore$ A (ANS)

Momentum and impulse



Two identical blocks, **X** and **Y,** are moving towards each other on a frictionless surface, with equal speeds. A piece of putty on the end of each block results in their sticking together on contact.

1980 Question 30, 1 mark 60%

What has happened to the total momentum of the two blocks as a result of the interaction?

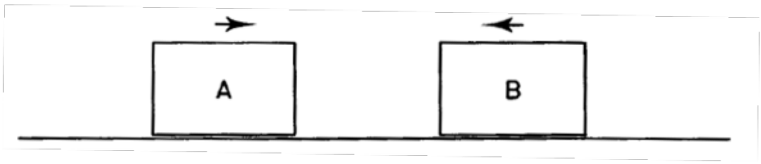
A. All the momentum has been lost; the collision is inelastic, so the momentum is dissipated as heat.

B. It has been transferred to the earth.

C. It is now stored in the molecules of the blocks and the putty.

D. Nothing has happened: it remains zero.

Initially the two identical blocks are moving together at the same speed. Therefore the initial momentum is zero, as they both have equal and opposite momentum.
Momentum is conserved in the collision, therefore the final momentum is zero. $\therefore$ ***D (ANS)***

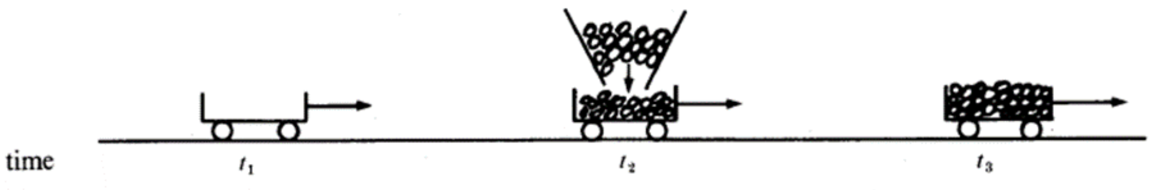


1980 Question 31, 1 mark 24%

Another pair of identical pucks, A and B, move towards each other on a frictionless surface with equal speeds. The pucks move apart after colliding.

During the interaction, $\frac{3}{4}$ of the total kinetic energy that the two pucks had before the collision is lost.

What is the value of the ratio $\dfrac{\text{magnitude of momentum of A before the collision}}{\text{magnitude of momentum of A after the collision}}$



If $\frac{3}{4}$ of the KE is lost during the collision, then only $\frac{1}{4}$ of the initial KE remains. Since KE is $\frac{1}{2}mv^2$, and the mass m is constant. This means that the final speed is $\frac{1}{2}$ of the original.

$\therefore$ ***2 (ANS)***

Momentum and impulse

An empty railway truck of mass *M* travels at constant speed *v* under a coal chute. At time t_2, a load of coal of mass *m* is dropped vertically into the truck.

1981 Question 27, 1 mark 67%

What is the speed of the truck immediately afterwards?

Momentum is conserved.

$\therefore p_f = p_i$

$\therefore (M + m)v_f = Mv$

$\therefore \boldsymbol{v_f = \dfrac{Mv}{m+M}}$ ***(ANS)***

1981 Question 28, 1 mark 69%

The gain in horizontal momentum of the coal is due to:

A. the impulse given to the coal by the truck.

B. the conversion of vertical kinetic energy into horizontal kinetic energy.

C. the force of gravity acting on the coal as it falls into the truck.

D. the conversion of potential energy into kinetic energy.

In the horizontal direction, the coal is given an impulse by the truck ***∴ A (ANS)***

1981 Question 29, 1 mark 68%

The falling coal had vertical momentum as it landed on the truck. What happened to this momentum?

A. It was transferred to the earth.

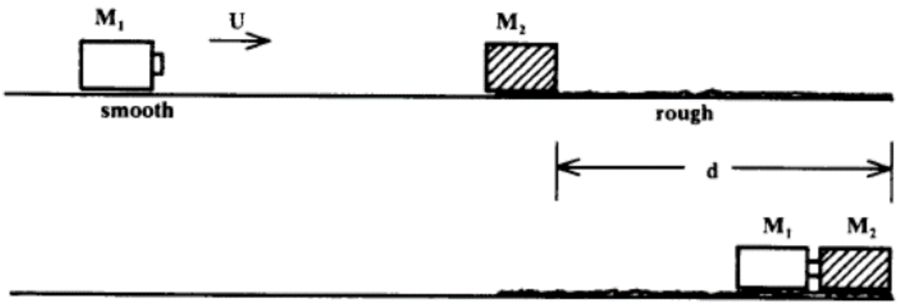
B. It was converted into horizontal momentum by the force of the walls of the truck on the coal.

C. It was lost as heat and sound as the coal came to rest relative to the truck.

D. It is stored in the coal in the form of potential energy'

The vertical momentum of the coal was transferred to the earth.

∴ A (ANS)



A block of wood, with a piece of putty attached (total mass M_1) is travelling at a constant speed *U* over a frictionless surface. It strikes a second block (M_2) and the two move off together with an initial velocity *V* and initial kinetic energy *K*. The blocks are subjected to a constant frictional force *F*, and come to rest after travelling a distance *d*.

1982 Question 11, 1 mark 83%

Write an expression for *V* in terms of M_1, M_2 and *U*.

Momentum and impulse

Momentum is conserved in all collisions.

$\therefore p_i = p_f$

$\therefore M_1U + M_2(0) = (M_1 + M_2)V$

$\therefore V = \dfrac{M_1U}{M_1 + M_2}$ ***(ANS***

1982 Question 12, 1 mark 71%

Which of the following statements about the total momentum of the blocks is correct?

A. Some of it is lost during the impact because the collision is inelastic; after that no momentum is lost, only kinetic energy.

B. Some of it is transferred (without loss) from M_1 to M_2 during the impact; the frictional force then causes the blocks to transfer momentum to the earth.

C. Some of it is lost during the impact, and the remainder is lost as the blocks travel along the rough surface.

D. The total momentum of the two masses remains the same.

Momentum is conserved during the collision, but some of M_1's momentum is transferred to M_2.
The frictional force then causes the blocks to lose energy and momentum. The momentum from the blocks is transferred to the earth.

$\therefore$ B (ANS)

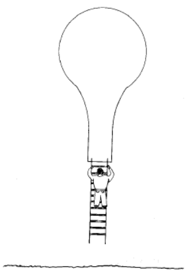
1982 Question 21, 1 mark 36%

An ice skater of mass 60 kg travelling **north** at 5 m s^{-1}, is carrying a parcel of mass 10 kg. The skater drops the parcel to the floor. What is the velocity of the skater now (magnitude and direction)?

The ice skater will continue with the same velocity.
During this interaction there weren't any forces acting, so there wasn't any work done, so the KE remained constant.

$\therefore$ 5.0 m s^{-1} North (ANS)

A man of mass *m* is standing on a rope ladder suspended below a free-floating balloon. The mass of the balloon and ladder is *M*. The balloon is stationary relative to the ground.



The man now climbs up the ladder at a speed *v* relative to the ground.

1983 Question 21, 1 mark 20%

With what speed relative to the ground does the balloon move, if at all?

Use conservation of momentum. Initially the momentum of the system is zero.
As the man climbs the ladder his momentum is given by $p = mv$
The balloon must have same momentum downwards,

$\therefore p_{balloon} = Mv_{balloon}$. $\therefore Mv_{balloon} = mv$

$\therefore v_{balloon} = \dfrac{mv}{M}$ ***(ANS)***

Momentum and impulse

1983 Question 22, 1 mark 69%

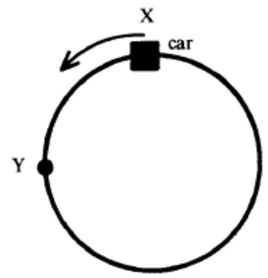
The man now stops climbing.

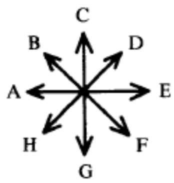
With what speed relative to the ground does the balloon now move?

Once the man stops climbing his momentum must be zero, therefore the balloon must also have zero momentum.

∴ 0 m s^{-1} (ANS)

The diagram below represents a car of mass 1000 kg travelling anticlockwise around a horizontal circular track of radius 200 m at a constant speed of 20 m s^{-1}.





KEY

Use the key to answer the next two questions.

1983 Question 24, 1 mark 87%

What is the direction of the car's momentum when it is at position X?

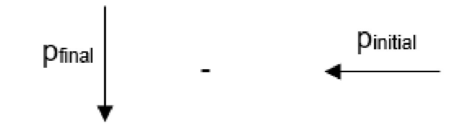
Use p = mv,
Therefore the direction of the momentum is the direction of the velocity at that point.
The velocity is tangentially to the left.

∴ A (ANS)

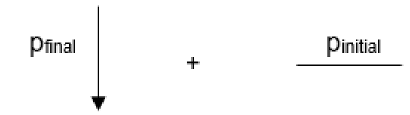
1983 Question 25, 1 mark 41%

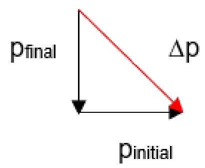
What is the direction of the change in momentum of the car when it moves from position X to position Y?

The change in momentum is always given by
$p_{final} - p_{initial}$



To subtract vectors add the negative (of the initial momentum)





∴ F (ANS)

Momentum and impulse

1983 Question 26, 1 mark 31%

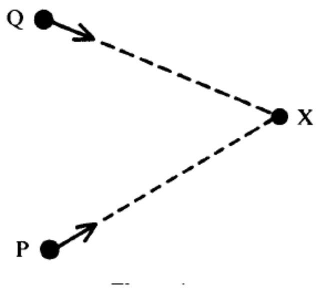
What is the magnitude of the change in momentum of the car when it moves from position X to position Y?

The triangle to find Δp is a 1:1: $\sqrt{2}$ triangle.

$\therefore \Delta p = \sqrt{2} \times 1000 \times 20$

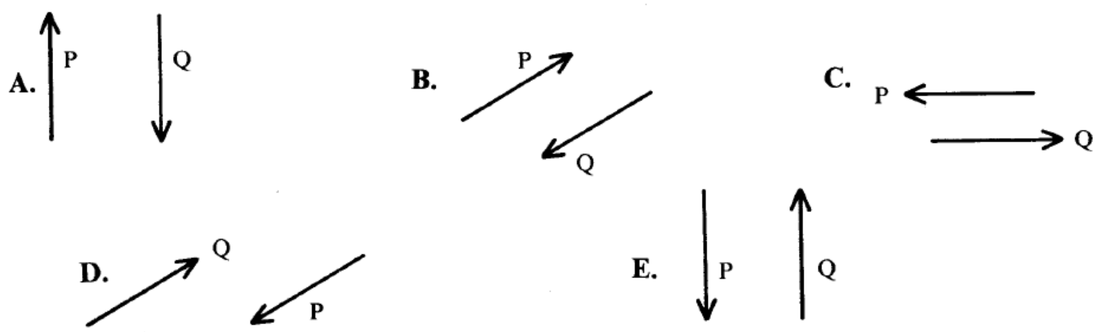
$\therefore \boldsymbol{\Delta p = 2.8 \times 10^{4}}$ ***kg m s^{-1} (ANS)***

Consider the following collision (shown below) between two identical ball-bearings (P and Q) travelling at the same speed and moving in the directions shown.



1984 Question 21, 1 mark 66%

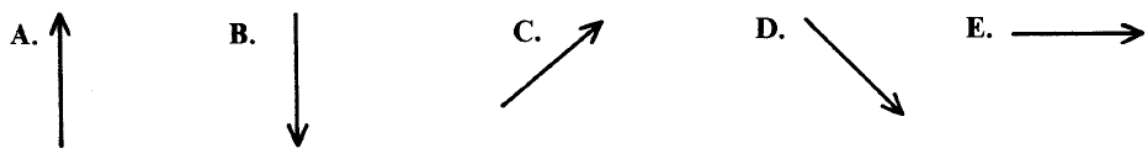
Assuming that the ball-bearings undergo an elastic collision at the point X, in which of the following diagrams do the arrows represent the change in momentum of each ball-bearing P and Q?



E (ANS)

1984 Question 22, 1 mark 46%

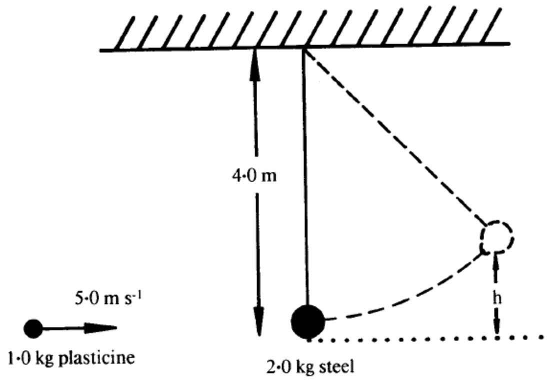
Which of the arrows below best represents the **impulse** applied to ball-bearing P by Q during the collision?



B (ANS)

Momentum and impulse

A 2.0 kg steel ball is hanging on a light inextensible string which is attached to a solid support. A 1.0 kg ball of plasticine is thrown with a horizontal velocity of 5.0 m s^{-1} at the hanging ball. It collides head-on with the hanging ball and sticks to it. In the following two questions take the acceleration due to gravity, g to be 10 m s^{-2}.



1984 Question 30, 1 mark 82%

What is the momentum of the two balls immediately after the collision?

Momentum is conserved, therefore the final momentum = initial momentum

$\therefore p_f = 1.0 \times 5.0$

$\therefore p_f = 5.0$ kg m s^{-1} (ANS)

1984 Question 32, 1 mark 43%

At the top of its motion the mass has no momentum. Which of the statements below best explains this situation?

A. Momentum is not conserved in inelastic collisions.

B. The momentum has been converted to potential energy.

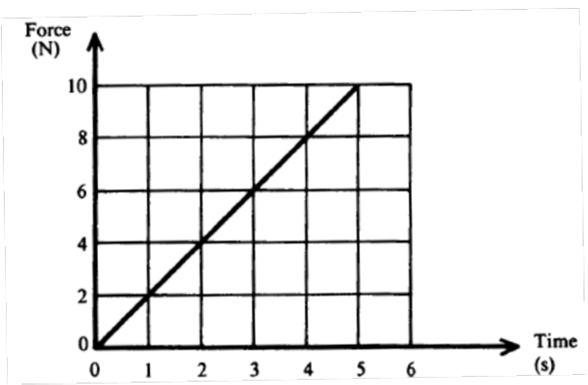
C. The momentum is stored as the tension in the string.

D. The momentum has been transferred to the earth via the support.

E. The momentum was dissipated as heat and sound during the collision.

Momentum is always conserved, in this case the initial momentum of the plasticine has been transferred to the Earth via the connection to the ceiling. ***$\therefore$ D (ANS)***

A body of mass 2.0 kg moves from rest, in a straight line, under the action of a net force that increases with time as shown in the graph below.



Momentum and impulse

1985 Question 12, 1 mark 52%

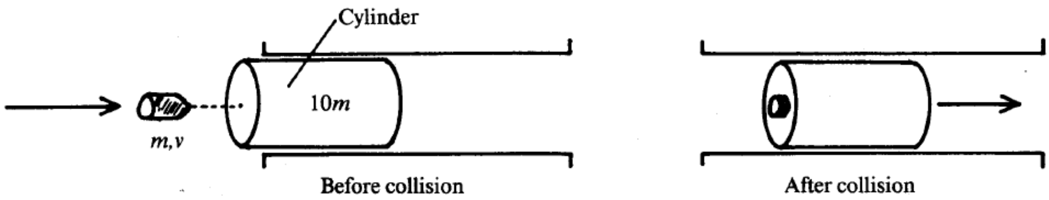
What is the change in momentum of the body in the first 5.0 s?

The change in momentum is given by the area under the graph.

$\Delta p = \frac{1}{2} \times 10 \times 5$

$\quad \mathbf{= 25\ N\ s\ (ANS)}$

A bullet of mass *m* and velocity *v* is fired directly at a solid cylinder of mass 10*m*, which can slide smoothly inside a horizontal tube as shown.



When the bullet hits, it sticks to the front of the cylinder, and the total mass slides forward as shown.

Answers to Questions 5 to 8 should be expressed in terms of *m* and *v*.

1986 Question 5, 1 mark

What is the velocity of the bullet-cylinder system after the collision?

Use conservation of momentum.

$\therefore mv = (m + 10m) \times v_{final}$

$\therefore \mathbf{v_{final} = \frac{v}{11}\ (ANS)}$

1986 Question 7, 1 mark

What impulse did the bullet give to the cylinder?

Impulse = change in momentum

$I = m \times \Delta v$

$\therefore I = 10m \times \frac{v}{11}$

$\therefore \mathbf{I = \frac{10mv}{11}\ (ANS)}$

1986 Question 8, 1 mark

If the collision occurred over a time interval *T*, what average force acted on the cylinder during the collision?

Use $I = F\Delta t$

$\therefore F = \frac{I}{\Delta t}$

$\therefore \mathbf{F = \frac{10mv}{11T}}$

Momentum and impulse

A person of mass 60 kg is held in the back seat of a car by a seat-belt. The belt is attached firmly to the body of the car.

The car, which is travelling.at a speed of 25 m s^{-1} collides with a tree, and stops. The passenger, still restrained by the seat-belt, stops moving 0.15 s after the initial impact.

1987 Question 28, 1 mark 82%

What is the magnitude of the impulse given to the passenger by the seat-belt?

Impulse is the change in momentum.

$\therefore \Delta p = m\,\Delta v$

$\therefore \Delta p = 60 \times 25$

$\therefore \boldsymbol{I = 1.5 \times 10^3}$ ***N s (ANS)***

1987 Question 29, 1 mark 78%

What is the average force exerted on the person by the seat-belt?

Use $F\Delta t = m\Delta v$

$\therefore F \times 0.15 = 1.5 \times 10^3$

$\therefore \boldsymbol{F = 1.0 \times 10^4}$ ***N (ANS)***

1987 Question 30, 1 mark 83%

After the collision, the passenger has no momentum. Which of the statements (A- D) below best describes what happened to the momentum that the passenger had originally?

A. It has been dissipated as heat and sound.

B. It has been stored as potential energy in the seat-belt which has stretched.

C. It has been transferred to the car and hence to the earth.

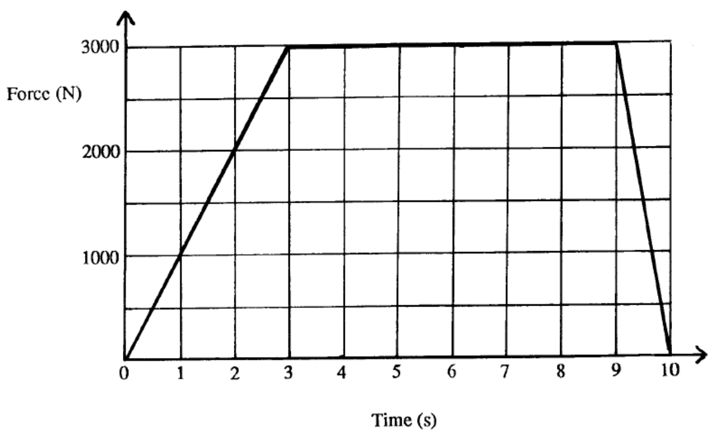
D. It has been recovered by the passenger, who recoils backward after the car stops.

Momentum is conserved. Therefore the passenger's momentum has been transferred to the Earth, via the car and the tree.

$\therefore$ ***C (ANS)***

A physicist is carrying out a study into the distance required for a car of mass 1000 kg to brake to a stop under various conditions. One test was carried out on a straight, level road.

The figure below shows the resultant force on the car as a function of time from the instant the brakes were applied (t = 0 s). The car came to a stop after 10.0 s.



Momentum and impulse

1988 Question 4, 1 mark

What was the magnitude of the change in momentum of the car in the 10.0 seconds?

Use $I = f\Delta t = m\Delta v$
Therefore the change in momentum is the area under the force v time graph.

$\therefore m\Delta v = \frac{1}{2}(6 + 10) \times 3000$

$\therefore \boldsymbol{m\Delta v = 2.4 \times 10^4}$ ***N s (ANS)***

1988 Question 5, 1 mark

What was the initial speed of the car at t = 0 s?

Use $m\Delta v = 2.4 \times 10^4$

$\therefore \Delta v = 2.4 \times 10^4 \div 1000$

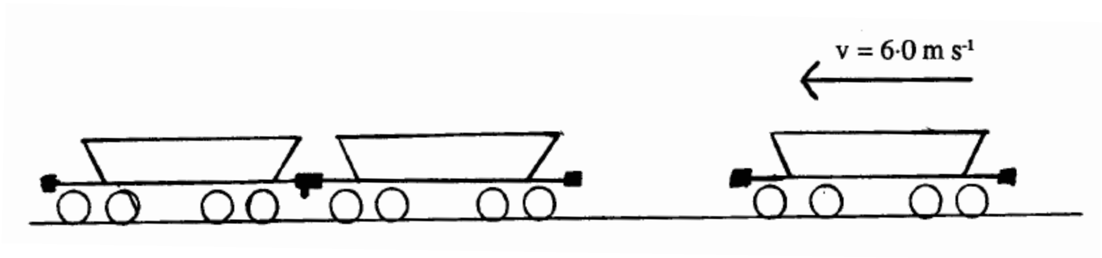
$\therefore \Delta v = 24$

$\therefore$ ***Initial speed = 24 m s^{-1} (ANS)***

During shunting, a railway truck is moving at 6.0 m s^{-1} towards two stationary trucks which are coupled together. This is shown in below.

Each of the trucks has a mass of 3.0×10^4 kg.

(Ignore any friction forces.)



The trucks collide and couple together.

1988 Question 16, 1 mark

What is the speed of the trucks after the collision?

Use conservation of momentum.

$\therefore p_{final} = p_{initial}$

$\therefore (3 \times 3.0 \times 10^4) \times v_{final} = 3.0 \times 10^4 \times 6.0$

$\therefore \boldsymbol{v_{final} = 2.0}$ ***m s^{-1} (ANS)***

1988 Question 17, 1 mark

Which of the statements (A - D) below is true for this collision?

A. Momentum and kinetic energy are conserved.

B. Neither momentum nor kinetic energy is conserved.

C. Kinetic energy is conserved but momentum is not conserved.

D. Momentum is conserved but kinetic energy is not conserved.

Momentum is always conserved. It is highly unlikely that KE was conserved in this collision (energy would have been lost to sound, heat and deformation).

$\therefore$ ***D (ANS)***

We can demonstrate this mathematically,

$KE_{final} = (3 \times 3.0 \times 10^4) \times 2^2$

$= 3.6 \times 10^5$ J

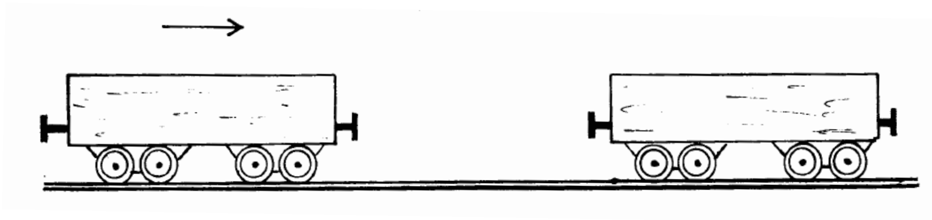
$KE_{initial} = 3.0 \times 10^4 \times 6^2$

$= 1.08 \times 10^6$ J

$\therefore KE_{final} < KE_{initial}$.

During shunting, a railway truck is moving with a constant velocity of 3.0 m s^{-1} towards a stationary truck as shown below.

Each truck has a mass of 2.0×10^4 kg. Ignore any friction forces.



The two trucks collide and couple together.

1989 Question 13, 1 mark

What is the total kinetic energy of the two trucks after the collision?

Use conservation of momentum to find the final speed.

$\therefore 2.0 \times 10^4 \times 3.0 = 4.0 \times 10^4 \times v$

$\therefore v = 1.5$ m s^{-1}

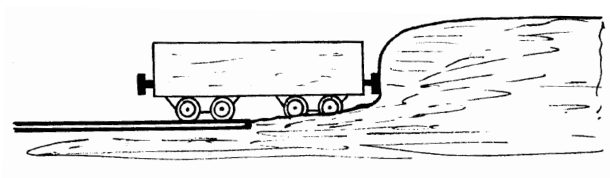
$KE_{final} = \frac{1}{2} \times 4.0 \times 10^4 \times 1.5^2$

$\boldsymbol{= 4.5 \times 10^4}$ ***J (ANS)***

1989 Question 14, 5 marks

(This is an extended answer question.)

A single truck runs off the end of a straight railway track and stops quickly. It comes to rest as shown below.



Discuss the forces on the truck and what happens to the momentum and the kinetic energy of the truck. A discussion of impulse should be included.

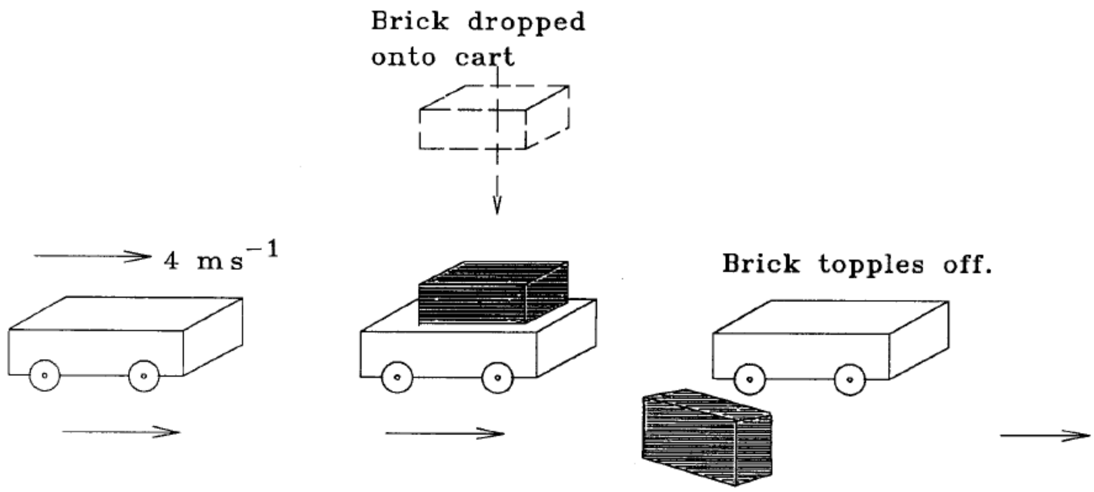
How would your answer differ if the truck had run onto a hard level surface and taken longer to come to rest?

The forces act on the truck to slow it down. The truck initially had momentum, but when it comes to rest its momentum has been transferred to the Earth. The KE it had initially has be dissipated as heat, sound and deformation of the ground it travelled over. The impulse on the truck is given by FΔt = mΔv, as Δt is quite small, and m and Δv are predetermined, then the forces acting must be large.

If the truck was allowed to run on a hard surface, then the forces acting to slow the truck down would be much less, so the time taken to stop the truck would be greater.

Momentum and impulse

Two young children, Dennis and Frank, are playing with some toy carts. Dennis pushes a cart towards Frank with a speed of 4 m s^{-1}. As the cart passes him, Frank drops a brick vertically onto it. The brick has a mass equal to that of the cart.



1990 Question 9, 1 mark

Just after Frank drops the brick onto it, the speed of the cart will be closest to

A. 1 m s^{-1}.

B. 4 m s^{-1}.

C. 2 m s^{-1}.

D. 8 m s^{-1}.

Momentum is conserved. In the horizontal the initial momentum is 4m, where m is the mass of the cart. After the collision p = 4m

$\therefore 4m = (m + m) \times v_{final}$

$\therefore v_{final} = 2\ m\ s^{-1}$

∴ C (ANS)

The vertical momentum of the block has been transferred to the Earth.

After the cart travels a further short distance, the brick topples sideways and falls off.

1990 Question 10, 1 mark

Just after the brick falls off, the speed of the cart is likely to be close to

A. the same speed as calculated in Question 9.

B. about half the speed calculated in Question 9.

C. about twice the speed calculated in Question 9.

D. close to zero.

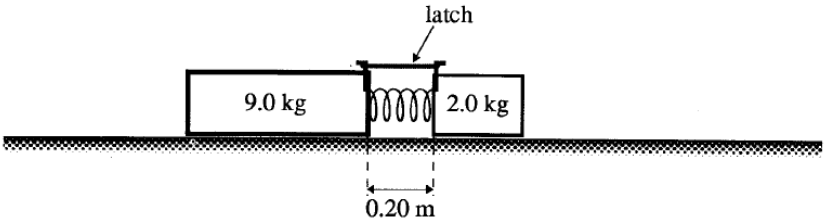
The horizontal momentum will remain constant, as the block topples sideways, it also is moving forward at 2.0 m s^{-1}, therefore the cart will continue with the same speed (in order to conserve momentum)

∴ A (ANS)

Momentum and impulse

A laboratory demonstration consists of two metal blocks of masses 2.0 kg and 9.0 kg which are coupled together with a latch. Between the blocks is a spring with a spring constant of 6.0×10^3 N m^{-1}. Its

normal length is 0.30 m, but in location it has been compressed to 0.20 m.



The blocks are placed at rest on a frictionless surface, and the latch quickly undone, so that the blocks fly apart.

1991 Question 15, 1 mark

What is the value of the ratio $\dfrac{\text{magnitude of momentum of 2.0 kg block}}{\text{magnitude of momentum of 9.0 kg block}}$

1991 Question 16, 1 mark

When the 9.0 kg block has moved 1.8 m, how far has the 2.0 kg block travelled?

Momentum is always conserved, therefore since the initial momentum is zero, the final momentum must be zero.
This means that both blocks must have the same momentum but in opposite directions.

$$\frac{\text{magnitude of momentum of 2.0 kg block}}{\text{magnitude of momentum of 9.0 kg block}} = 1$$

$\therefore$ ***1 (ANS)***

Most sports safety helmets are designed to protect the head during impact with the ground following a fall. A helmet usually consists of a liner of polystyrene foam about 2.5 cm thick which is moulded to fit the shape of a human head. Some helmets are covered with a hard outer shell of plastic. According to a consumer magazine, the hard shell protects the foam liner but 'does not contribute greatly to the impact absorption of the helmet'.

1993 Question 7, 2 marks

The use by the consumer magazine of the term 'impact absorption' is not correct physics terminology. In terms of **one or more** of the physics concepts listed below, describe how a helmet protects a person's head during an impact with the ground.

- Force, impulse, energy, momentum, acceleration

The purpose of the helmet is to reduce the size of the average force on the head. Since the change in kinetic energy = $F_{(average)} \times \Delta x$*, any increase in the compression will result in a smaller* $F_{(average)}$*.*

Alternatively, since the change in momentum = $F_{(average)} \times \Delta t$*, any increase in the time of collision will result in a smaller* $F_{(average)}$*. The use of the foam liner increases both the compression distance and the time of collision. Hence, the size of the average force on the head is reduced. Alternatively, it can be said that the average deceleration of the head is decreased, thus lessening the chance of injury.*

Momentum and impulse

A car is stationary at a stop sign when it is hit directly from behind by a truck of mass 3000 kg which was travelling at a speed of 9 m s^{-1} immediately before the collision. The two vehicles lock together and move forward with an initial speed of 6 m s^{-1}.

1994 Question 6, 1 mark

What is the mass of the car?

Momentum is conserved, so $p_i = p_f$
$\therefore$ $p_i = 3000 \times 9.0 + m \times 0 = 27\,000$ (to the right, by my definition).

$\therefore$ $p_f = 27\,000$ (to the right) $= (3000 + m) \times 6$
$\therefore$ $27\,000 = 3000 \times 6 + 6m$
$\therefore 27\,000 = 18\,000 + 6m$
$\therefore$ $6m = 9000$
$\therefore$ $m = 1500$ kg (ANS)

Both drivers were wearing correctly adjusted seatbelts at the time of the accident, and the vehicles had strong supporting seat backs with head restraints.

1994 Question 7, 1 mark

Which statement (A - D) below best describes the forces arising from the impact, which act on the drivers?

A. Each driver felt an increased force due to the seatbelts.

B. The driver of the car felt an increased force due to the seatbelt, but the driver of the truck felt an increased force due to the back of the seat.

C. Each driver felt an increased force due to the back of the seat.

D. The driver of the truck felt an increased force due to the seatbelt, but the driver of the car felt an increased force due to the back of the seat.

The driver of the truck slowed down, so the force acting on them was backward, this force was provided by the seatbelt. The driver of the car accelerated forwards, this acceleration was due to the force of the back of the seat on the driver.

$\therefore$ D (ANS)

Each driver had a mass of 72.0 kg. During the collision, the driver of the car experienced an average force of 8 000 N.

1994 Question 8, 1 mark

How long did the collision take?

Use the impulse equation to solve this.

$\therefore F\Delta t = m\Delta v$
$\therefore$ $8000 \times \Delta t = 72.0 \times 6$
$\therefore$ $\Delta t = 0.054$ sec
$\therefore$ 54 ms (ANS)

Momentum and impulse

1994 Question 9, 1 mark

What was the magnitude of the force experienced by the driver of the truck?

Use the impulse equation to solve this.

$\therefore F\Delta t = m\Delta v$

$\therefore F \times 0.054 = 72.0 \times 3$

$\therefore F = 4\ 000$

$\therefore$ ***4 000 N (ANS)***

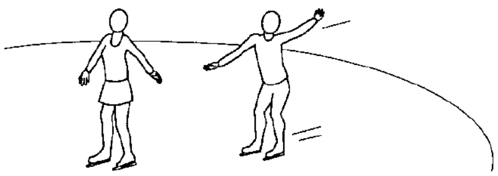
1994 Question 10, 2 marks

If the car had been designed with a crumple zone, explain, in correct physics terms, why this might reduce the risk of injury to the driver.

The crumple zone is designed to increase the time of the collision. This increase in the time of collision reduces the forces acting significantly.
From the Impulse equation $F\ \Delta t = m\ \Delta v$ it can be seen that an increase in Δt for a fixed value of $m\Delta v$ will lead to a decrease in F.
Stiff materials result in shorter contact times, the crumple zone results in longer contact times.
Injuries to the driver are caused by contact forces, i.e seatbelt, steering wheel, doors, and other panels. The larger these forces are, the greater the risk that parts of the body will undergo forces that will push the body beyond its elastic limit, resulting in injury.

John, of mass 70 kg, and Mary of mass 60 kg, are practising for an ice-skating competition. In the

questions below, assume that the ice provides a frictionless surface, and that the skaters do not push against the ice.



In the figure above, Mary is standing at rest on the ice and John is approaching her with a speed of 4.0 m s^{-1}.

1995 Question 4, 1 mark 90%

What is the magnitude of John's momentum before he reaches Mary?

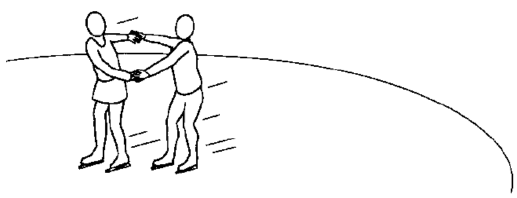
Momentum $= m \times v$

$= 70 \times 4.0$

$= 280$ kg m s^{-1}

$= 2.8 \times 10^2$ kg m s^{-1} ***(ANS)***

In the figure below, John and Mary are moving together in the direction that John was moving before he linked hands with Mary.



Momentum and impulse

1995 Question 5, 1 mark 75%

What is the speed of the pair?

Momentum is conserved.
Hence, momentum of the pair

$m \times v = 280$

$\therefore (60 + 70) \times v = 280$

$\therefore 130v = 280$

$\therefore v = 2.15 \text{ m s}^{-1}$ ***(ANS)***

Without pushing or pulling, John and Mary let go of each other.

1995 Question 6 2 marks 45%

Describe the subsequent motions of the two skaters. Your answer should discuss the speed and direction of motion of each skater. You should justify your answer by referring to any relevant physics principles.

John and Mary will both continue in the same direction at the same speed because a mass will continue in a state of constant velocity unless it is acted upon by some external force. John and Mary do not exert any force on each other (no pushing or pulling).

A ball of mass 0. 100 kg is dropped vertically on to a hard surface, reaching a speed of 12 m s^{-1} just before hitting the surface. It rebounds vertically at an initial speed of 8.0 m s^{-1}. The contact between ball and surface lasts for a time of 0.0050 s.

1996 Question 16, 1 mark 45%

Calculate the magnitude of the change in momentum of the ball during the time of contact.

The change in momentum is given by $p_f - p_i$

$= mv_f - mv_i$

$\boldsymbol{v} - \boldsymbol{u} = 20 \text{ m s}^{-1}$ *up.*

$\therefore \Delta p = 0.100 \times 20$

$\boldsymbol{= 2.0 \text{ kg m s}^{-1}}$ ***(ANS)***

1996 Question 17, 1 mark 45%

Calculate the magnitude of the average net force exerted on the ball during the collision.

Use $F \Delta t = m \Delta v$

$\therefore F = \dfrac{2.0}{0.005}$

$= 400$

$\therefore \boldsymbol{F = 4.0 \times 10^2 \text{ N}}$ ***(ANS)***

Momentum and impulse

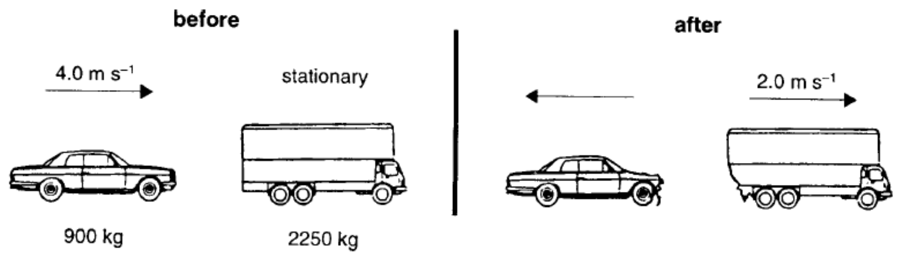
A car of mass 900 kg, travelling on a horizontal road with a speed of 4.0 m s^{-1}, runs into the rear of a stationary truck of mass 2250 kg as shown below. Immediately after the collision the truck moves forward with a speed of 2.0 m s^{-1} and the car rebounds in the opposite direction.

In modelling this collision you should assume that

• there is no driving force from either engine during the collision

• no braking takes place during the collision

• the car and truck remain in a straight line.



1997 Question 6, 3 marks 75%

What is the speed of the car immediately after the collision?

Momentum must be conserved, so $p_i = p_f$
$\therefore\ p_i = 900 \times 4.0 + 2250 \times 0 = 3600$ *to the right.*

$\therefore\ p_f = 3600$ *(to the right)* $= 2250 \times 2.0 - 900 \times v$

$$\therefore\ v = \frac{4500 - 3600}{900}$$

$\therefore$ ***v = 1.0 m*** $\boldsymbol{s^{-1}}$ ***(ANS)***

You need to be careful to consider the direction of the momenta.

1997 Question 7, 5 marks 40%

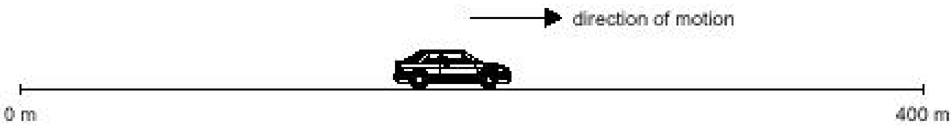
This was an **inelastic** collision. Explain the meaning of the word inelastic and show, using calculations, that this collision was inelastic.

Inelastic means that the kinetic energy is not conserved in this collision. In this case the final KE is less than the initial KE.

$KE_i = \frac{1}{2} \times 900 \times 4.0^2 + \frac{1}{2} \times 2250 \times 0$
$= 7200$ J
$KE_f = \frac{1}{2} \times 900 \times 1^2 + \frac{1}{2} \times 2250 \times 2.0^2$
$= 450 + 4500$
$= 4950$ J.
The Initial KE - Final KE $= 7200 - 4950$
$= 2250$ J.
$\therefore$ *2250 J of energy were lost in this collision.*
To gain the 5 marks you needed to show all this working out.

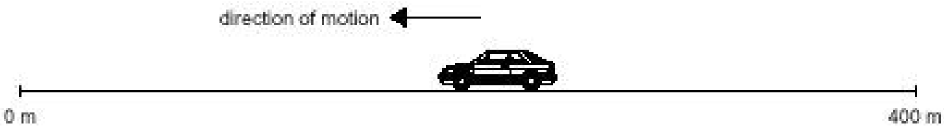
Momentum and impulse

The “standing 400 m” time for a car is the time that it takes to travel 400 m on a level road, accelerating from rest. The standing 400 m time of a car was 16.0 s.



The test on the car was repeated in the **opposite direction** and the standing 400 m time was

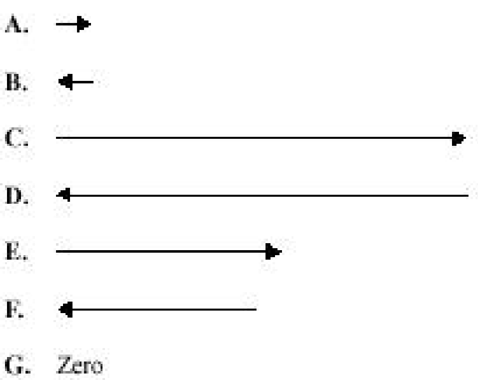
18.0 s.



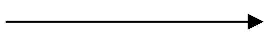
The momentum of the car at the end of the first 400 m may be represented in magnitude and direction by the vector shown below.

2000 Question 3, 1 mark *29%*

Which **one** of the vectors **(A – G**) best represents the **momentum change** of the car, between the **end** of the first and the **end** of the second run?

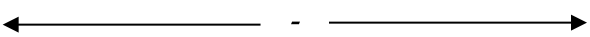


This question is testing your understanding of vectors using momentum.
The cars initial momentum was to the right.

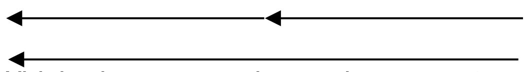


The cars final momentum was to the left.

The final momentum minus the initial momentum gives a change in momentum.
$\Delta p = p_f - p_i$. *You are expected to do this with the vectors.*
Thus:



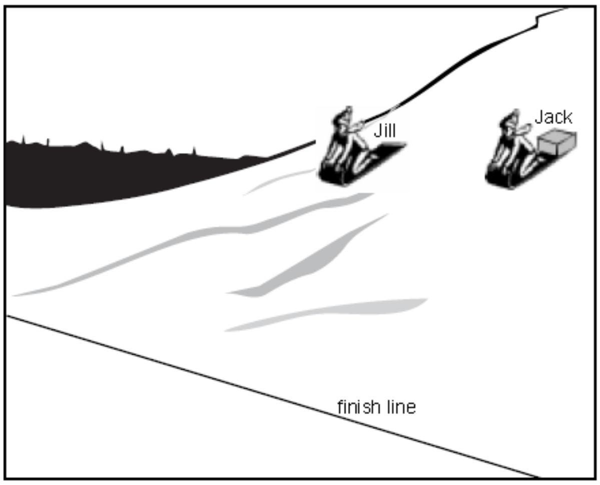
This minus just changes the direction of the vector that follows it. Therefore you get:



Which gives you a change in momentum like this
*.: **D (ANS)***

Momentum and impulse

Jack and Jill are racing their toboggans down an icy hill. Jack and Jill are of similar mass and are using the same type of toboggan. When Jack is a certain distance from the end of the race they are travelling with the same velocity. Jack is behind Jill and decides that if he is going to win the race, he must lighten his toboggan, so he pushes a box containing their ice-skating gear off the side of his toboggan.



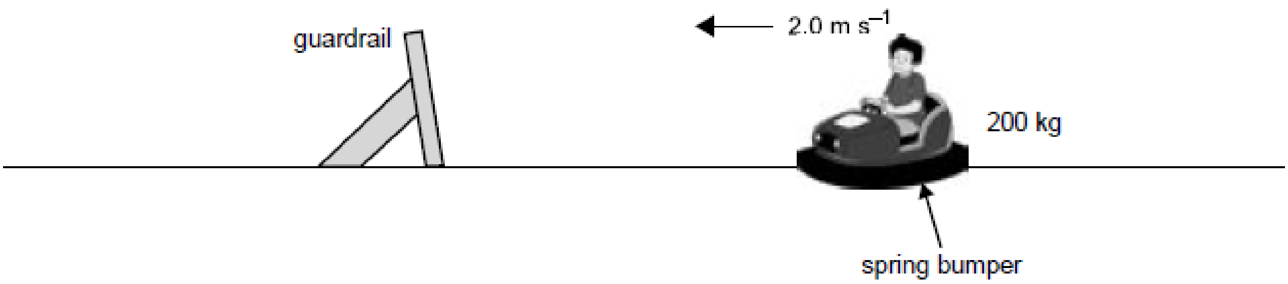
2001 Question 11, 4 marks 23%

Explain, giving clear reasons, whether this will be a successful way for Jack to catch up to Jill and help him win the race.

This question is worth 4 marks, so you should give at least four distinct answers. You must also answer the question in a clear manner. It is always useful to put your answer in point form. This question was meant to be a momentum question, but a lot of students used energy and forces to try to explain the answer. It was much simpler as a momentum question.

- *If Jack pushes the box off the side of his toboggan, then it will have gained sideways momentum.*
- *As momentum is always conserved, then Jack also gains sideways momentum, but in the opposite direction.*
- *The box will still have its original downward momentum, so it will continue down next to Jack*
- *From a conservation of momentum, there will be no change in the forward momentum of the box or toboggan*
- *Lightening his toboggan will not cause Jack to gain or lose downhill momentum, so his speed will stay the same.*
- *If Jack really wanted to win the race, then he needed to project the box backwards*
- *Jill will remain in front and win the race.*

Kim is driving a dodgem car. He is travelling at 2.0 m s–1 when he hits an oil patch and collides head-on with the guardrail. The dodgem car (shown below) has a spring-loaded bumper. After the collision the dodgem car rebounds directly backwards along the same line at a speed of 2.0 m s^{-1}. The spring constant of the bumper is 3.2 × 10^5 N m^{-1} and the mass of Kim and the dodgem car is 200 kg.



Momentum and impulse

The law of conservation of momentum (for an isolated system) is a fundamental law of physics that applies to all collisions.

2003 Question 7, 4 marks 28%

Describe how you would show that the collision between the dodgem car and the guardrail satisfies the law of conservation of momentum. In particular, address these three aspects.

Initial momentum of dodgem car

Final momentum of dodgem car

Given the previous answers, explain how momentum is conserved.

Before the collision: The initial momentum was p = 200 × 2 = 400 kg m s^{-1} to the left.

After the collision: the final momentum was
400 kg m s^{-1} to the right.
∴ the change in momentum (of the dodgem car) is given by $p_{final} - p_{initial}$ = 800 kg m s^{-1} to the right.

For momentum to be conserved, the guardrail must also have had a change in momentum of 800 kg m s^{-1}, but this would have been to the left. This change in momentum has been transferred to the Earth.

A delivery van of mass 1200 kg, travelling south at 20 m s^{-1}, collides head-on with a power pole. The impact crushes the crumple zone of the van by 0.60 m bringing the van to rest against the pole.

2004 Question 5, 2 marks 65%

Calculate the time for the impact.

$$s = \frac{v+u}{2}t, \qquad 0.6 = \frac{20}{2} \times t, \qquad t = 0.06\ s$$

2004 Question 6, 3 marks 43%

Calculate the initial momentum and final momentum of the van and explain how momentum has been conserved in this collision.

$P_{initial}$ = 1200 × 20
= 2.4×10^4
P_{final} = 0, since the van comes to rest.

∴ 2.4×10^4 kg m s^{-1} of momentum is transferred to the Earth via the power pole.

The following quote was taken from the NASA web site.

To safely reach the surface of Mars, a spacecraft must decelerate from 21 000 km h^{-1} in a matter of minutes and be able to protect its payload as it lands. The Mars Exploration Rovers of 2003 will use a proven airbag system.

Both physics and non-physics students alike would agree that airbags result in a ‘softer collision’.

2004 Question 11, 3 marks 50%

Explain the meaning of the term softer collision in the context of an airbag.

The concept of a softer collision is one where the forces acting are less.
Using $F\Delta t = m\Delta v$, to make the force small we need to increase the collision time. This is because the change in speed will be fixed as it must decelerate from 21 000 km hr^{-1} to zero, and the mass of the spacecraft is also a constant.
$\therefore$ In this equation the RHS is constant, so to make F smaller we need to increase the time of the collision. Airbags are designed to inflate just before the collision and then to collapse. This collapse takes some time, therefore lengthening the time of collision.

The figure shows a space shuttle docking with the international space station.

Imagine that you are an astronaut floating in space **at rest relative to the international space station**. You watch the space shuttle, of mass 6000 kg, dock. You observe the shuttle approaching -the space station with a speed of 5.00 m s^{-1}. After docking, the space station's speed has increased by 0.098 m s^{-1}.

Question 10, 3 marks 37%

Show that the mass of the space station is 3 × 10^5 kg.

From conservation of momentum

$\Sigma p_i = \Sigma p_f$

$\therefore 6000 \times 5 + M \times 0 = (6000 + M) \times 0.098$

$\therefore 30000 = 588 + 0.098 \times M$

$\therefore 29412 = 0.098\ M$

$\therefore\ M = 300122$

$\therefore\ \mathbf{M = 3.0 \times 10^5\ kg\ (ANS)}$

After first making contact, it takes 20 s for the shuttle to come to rest with the space station.

2006 Question 11, 3 marks 37%

$F\,\Delta t = m\Delta v$

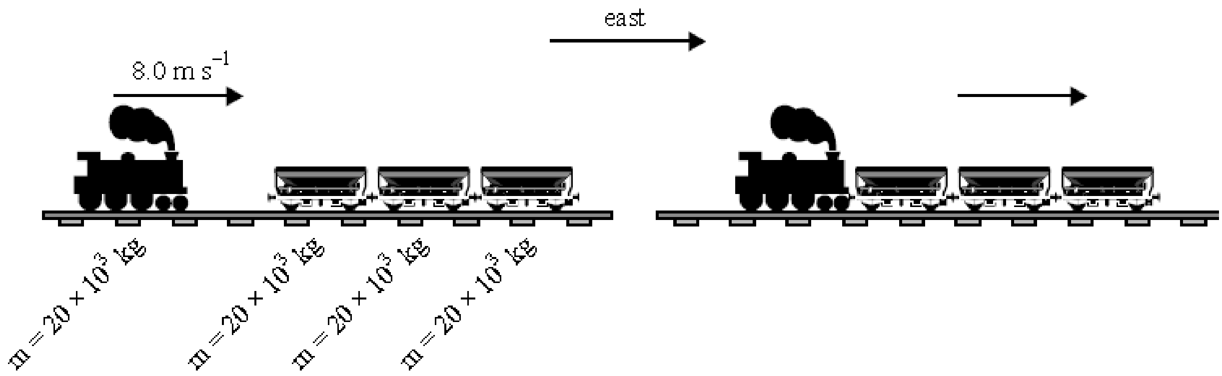
$\therefore F \times 20 = 6000 \times (5 - 0.098)$

$\therefore F = \dfrac{6000 \times 4.902}{20}$

$\therefore F = 1470.6$ N

$\therefore$ **$F = 1.47 \times 10^3$ N (ANS)**

A locomotive, of mass 20×10^3 kg, moving at 8.0 m s^{-1} east, collides with and couples to three trucks, each of mass 20×10^3 kg, initially stationary, as shown.



79%

What is the speed of the coupled locomotive and trucks after the collision?

You must show your working.

Momentum is conserved in this collision.

$\therefore p_i = p_f$

$\therefore 20 \times 10^3 \times 8 = 80 \times 10^5 \times v$

$\therefore$ **$v = 2$ m s^{-1} (ANS)**

2008 Question 9, 3 marks 53%

What is the impulse given **to** the locomotive **by** the trucks in the collision (magnitude and direction)? You must show your working.

The impulse given to the locomotive by the trucks is equal and opposite to the impulse given to the trucks by the locomotive.
Impulse on the trucks is the change in momentum of trucks.

$= m\Delta v$

$= 60 \times 10^3 \times 2$

$= 1.2 \times 10^5$ kg m s^{-1} West (ANS)

Momentum and impulse

2008 Question 10, 3 marks 73%

Was this collision elastic or inelastic?

Support your conclusion by appropriate calculation.

If the collision is elastic, then $KE_{final} = KE_{initial}$.

$$
\begin{aligned}
KE_{initial} &= \tfrac{1}{2}mv^2 \\
&= \tfrac{1}{2} \times 20 \times 10^3 \times 8^2 \\
&= 64 \times 10^4 \\
&= 6.4 \times 10^5 \\
KE_{final} &= \tfrac{1}{2}mv^2 \\
&= \tfrac{1}{2} \times 80 \times 10^3 \times 2^2 \\
&= 1.6 \times 10^5 \\
KE_{final} &< KE_{initial}
\end{aligned}
$$

$\therefore$ *KE is lost*

$\therefore$ Collision is inelastic (ANS)

During the collision, the magnitude of the average force exerted by the locomotive on the trucks is FL and the magnitude of the average force exerted by the trucks on the locomotive is FT.

2008 Question 11, 2 marks 51%

Will FL be greater, equal to, or less than FT? Explain your answer.

The magnitude of the impulse on both the locomotive and the trucks is the same.

Since $I = F\,\Delta t$

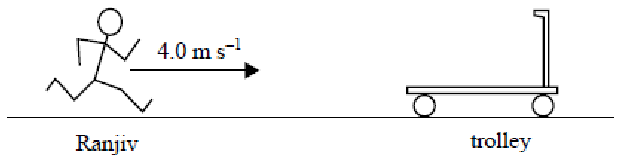
and the time of the collision is the same for both.

$\therefore$ $\boldsymbol{F_L = F_T}$ ***(ANS)***

(This is an example of Newton's Third Law, where $F_{A\ on\ B} = -F_{B\ on\ A}$)

The following information relates to Questions 1 and 2.

Ranjiv, who has a mass of 80 kg, is running with a speed of 4.0 m s^{-1} as he steps onto a stationary trolley of mass 40 kg as shown below. Ranjiv holds on to the trolley. Ranjiv and the trolley then move forward together in the same direction.



84%

What is the speed of the trolley as soon as Ranjiv is on board?

This is a conservation of momentum question. The momentum before will equal the momentum after the "collision".

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$, *since the velocity of the cart is equal to the velocity of Ranjiv after he is aboard.*

$$80 \times 4 + 40 \times 0 = v(80 + 40)$$

$$\therefore v = \frac{320}{120}$$

$\therefore$ *v* = ***2.7 m s^{-1} (ANS)***

Momentum and impulse

2009 Question 2, 3 marks 78%

Is this collision between Ranjiv and the trolley elastic or inelastic? Write your answe, **and** justify it with a calculation.

$KE_{initial} = \frac{1}{2} \times 80 \times 4^2 = 640$ J

$KE_{final} = \frac{1}{2} \times 120 \times 2.7^2 = 427$ J

The final KE is less than the initial KE, therefore the collision is inelastic.

The following information relates to Questions 16–17.

Physics students are conducting a collision experiment using two trolleys, m_1 of mass 0.40 kg and m_2 of mass 0.20 kg.

· Trolley m_1 has a light spring attached to it. When uncompressed, this spring has a length of 0.20 m.

· Trolley m_1 is initially moving to the right. Trolley m_2 is stationary.

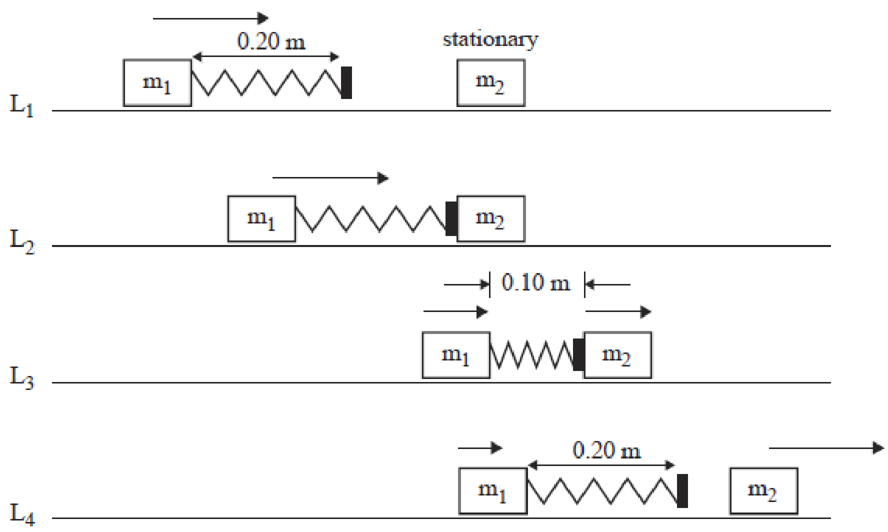
· The trolleys collide, compressing the spring to a length of 0.10 m.

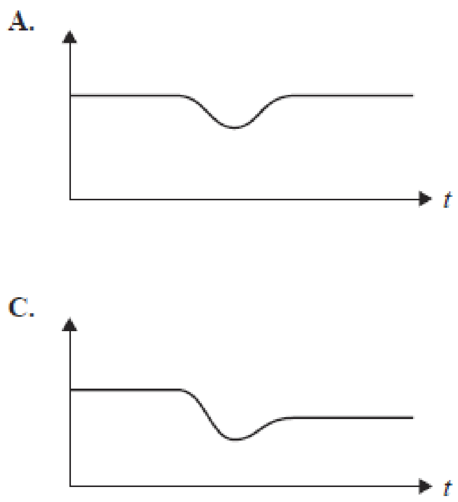
· The trolleys then move apart again, and the spring reverts to its original length (0.20 m), and both trolleys move off to the right.

· The collision is elastic.

· The trolleys do not experience any frictional forces.

The situation is shown below.





Which graph best shows how the total momentum of the system varies with time before, during and after the collision? Explain your answer.

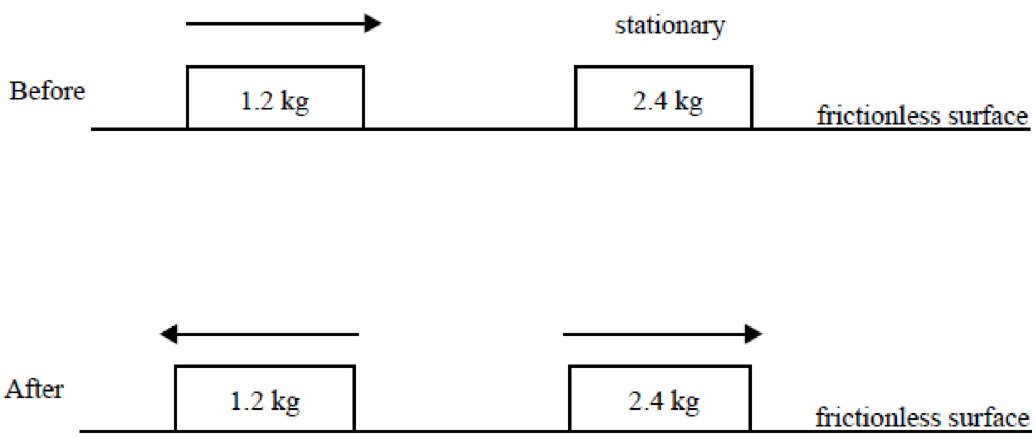
Momentum is always conserved.
*∴ **B (ANS)***

2010 Question 17, 2 marks 37%

If the collision had been inelastic, which graph would best show how the magnitude of the total momentum of the system varies with time before, during and after the collision? Explain your answer.

Momentum is always conserved. This does not depend on whether the collision is elastic or in-elastic.
*∴ **B (ANS)***

A 1.2 kg block moves to the right along the frictionless surface and collides elastically with a stationary block of mass 2.4 kg as shown below.



28%

After the collision, the momentum of the 2.4 kg block is **greater** than the momentum that the

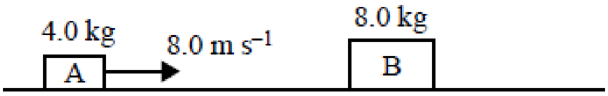
1.2 kg block had before the collision. Explain why the greater momentum of the 2.4 kg block is consistent with the principle of conservation of momentum.

Momentum and impulse

$p_0 = 1.2u \quad p_f = 2.4v_2 - 1.2v_1 \quad p_0 = p_f \quad 1.2u = 2.4v_2 - 1.2v_1$

$2.4v_2 = 1.2u + 1.2v_1 \; therefore \; 2.4v_2 > 1.2u$

Block A, of mass 4.0 kg, is moving to the right at a speed of 8.0 m s^{-1}, as shown below. It collides with a stationary block, B, of mass 8.0 kg, and rebounds to the left. Its speed after the collision is 2.0 m s^{-1}.



2015 Question 1a, 2 marks 43%

Momentum is conserved, so the final momentum is equal to the initial momentum.
p_i = 4.0 × 8.0 + 8.0 × 0
∴ *p_i = 32.0*

∴ *32.0 = 8.0 × v – 4.0 × 2*
∴ *p_f = 32.0*
∴ *32 = 8v – 8*
∴ v = 5 m s^{-1} (ANS)

2015 Question 1b, 2 marks 66%

Explain whether the collision is elastic or inelastic. Include some calculations in your answer.

For an elastic collision the final KE = Initial KE.
Initial KE = $\frac{1}{2}mv^2$
= $\frac{1}{2} \times 4 \times 8^2$
= 128 J
Final KE = $\frac{1}{2}mv^2 + \frac{1}{2}mv^2$
= $\frac{1}{2} \times 4 \times 2^2 + \frac{1}{2} \times 8 \times 5^2$
= 8 + 100
= 108 J
∴ Inelastic, as KE is lost.

2015 Question 1c, 3 marks 62%

What are the magnitude, unit and direction of the impulse by block B on block A?

The impulse by block B on block A is the change in momentum of block A. The direction of the change in momentum will be given by the final momentum minus the initial momentum. This is in the direction of the final momentum.
The magnitude of the impulse by block B on block A i the same as the magnitude of the impulse by block A on Block B. For Block B, its initial momentum was zero, therefore its change in momentum is p_f.
∴ *p_f = m Δv*
∴ *p_f = 8 × 5*
∴ *p_f = 40*
∴ I = 40 N s left (ANS)

Momentum and impulse

The engine, of mass 20 tonnes moving to the right at 2.0 m s^{-1}, collides with but does not couple with the stationary wagon of mass 10 tonnes. After the collision, the wagon moves off to the right at 2.0 m s^{-1}.

2016 Question 1e, 3 marks 77%

Calculate the velocity (magnitude and direction) of the engine after the collision. Show your working.

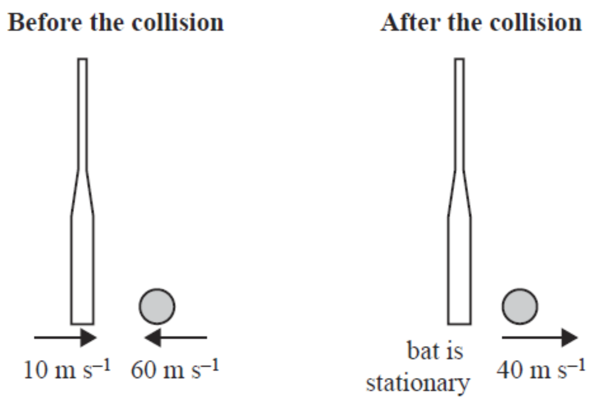
Momentum is conserved.
$\therefore p_i = p_f$
$\therefore 20\,000 \times 2 + 10\,000 \times 0 = 20\,000 \times v + 10\,000 \times 2$
$\therefore 40\,000 = 20\,000 \times v + 20\,000$
$\therefore 20\,000 = 20\,000 \times v$
$\therefore$ ***v = 1 m s^{-1} Right (ANS)***

Students are using high-speed photography to analyse the collision between a bat and a ball. The experiment is arranged so that the bat and the ball are both moving horizontally just before and just after the collision, as shown below.

Assume that the bat and the ball are point masses.

The students record the following measurements.

mass of bat	2.0 kg
mass of ball	0.2 kg
speed of bat immediately before collision	10 m s^{-1} (bat is stationary after collision)
speed of ball immediately before collision	60 m s^{-1} (towards bat)
speed of ball immediately after collision	40 m s^{-1} (away from bat)
time ball is in contact with bat	0.010 s



2019 NHT Question 7a, 3 marks

Calculate the magnitude of the impulse given by the bat to the ball. Include an appropriate unit. Show your working.

Impulse = mΔv
For the ball = 0.20 × (40 - - 60)
= 0.20 × 100
= 20 kg m s^{-1} (ANS)

2019 NHT Question 7b, 2 marks

Calculate the average force of the bat on the ball during the collision. Show your working.

Use $I = F\,\Delta t$

$\therefore\ 20 = F \times 0.010$

$\therefore\ \boldsymbol{F = 2.0 \times 10^3}$ ***N (ANS)***

2019 NHT Question 7c, 2 marks

Use calculations to determine whether the collision between the bat and the ball is elastic or inelastic. Show your working.

Initial KE

$KE_i = \frac{1}{2} m_{bat}u^2 + \frac{1}{2} m_{bat}u^2$

$= 0.5 \times 2.0 \times 10^2 + 0.5 \times 0.2 \times 60^2$

$= 100 + 360$

$= 460$ J

Final KE

$KE_f = \frac{1}{2} m_{bat}v^2 + \frac{1}{2} m_{bat}v^2$

$= 0 + 0.5 \times 0.2 \times 40^2$

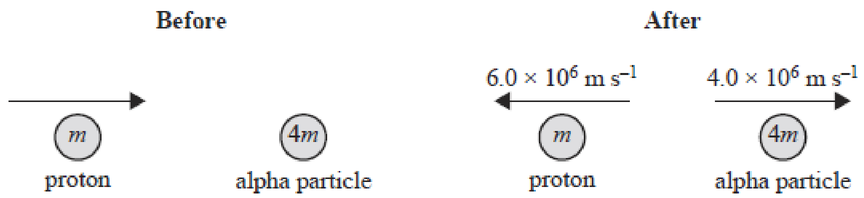
$= 160$ J

Therefore kinetic energy is lost so collision is inelastic

Inelastic (ANS)

A proton in an accelerator detector collides head-on with a stationary alpha particle, as shown below. After the collision, the alpha particle travels at a speed of 4.0×10^6 m s^{-1}. The proton rebounds at

6.0×10^6 m s^{-1}.



2019 Question 9, 3 marks 59%

Find the speed of the proton before the collision, modelling the mass of the alpha particle, 4*m*, to be equal to four times the mass of the proton, *m*. Show your working. Ignore relativistic effects.

Momentum is conserved in all collisions.

$\therefore\ p_i = p_f$

You need to be very careful with the sign convention for your directions.

$p_f = m \times -6.0 \times 10^6 + 4m \times 4.0 \times 10^6$

$\therefore\ p_f = m \times 10 \times 10^6$ *to the right.*

$\therefore\ p_f = m \times 1.0 \times 10^7$ *to the right.*

$\therefore\ p_i = m \times v_{proton}$

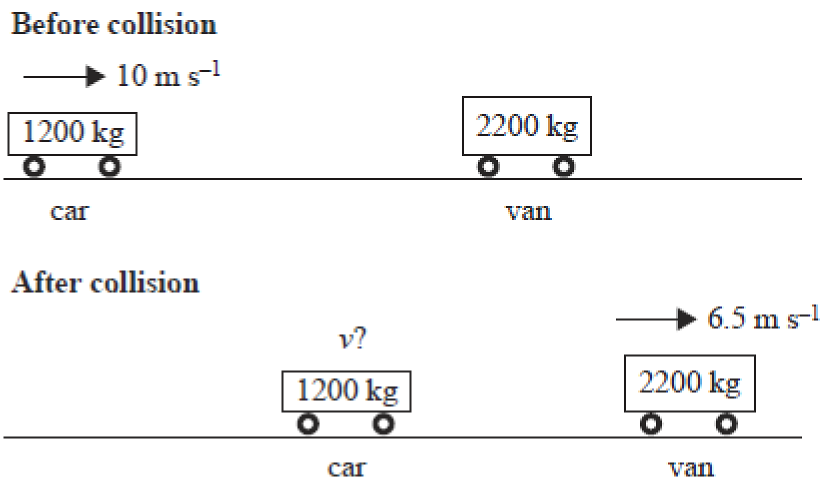
$= m \times 1.0 \times 10^7$

$\therefore\ \boldsymbol{v_{proton} = 1.0 \times 10^7}$ ***m s^{-1} (ANS)***

The direction is not required as the question specifies 'find the speed'.

Momentum and impulse

Jacinda designs a computer simulation program as part of her practical investigation into the physics of vehicle collisions. She simulates colliding a car of mass 1200 kg, moving at 10 m s^{-1}, into a stationary van of mass 2200 kg. After the collision, the van moves to the right at 6.5 m s–1. This situation is shown below.



2020 Question 10a, 4 marks 83%

Calculate the speed of the car after the collision and indicate the direction it would be travelling in.

Show your working.

The initial momentum is $p = mv$

$\therefore p = 1200 \times 10$

$\therefore p = 1.2 \times 10^4$

Final momentum = 1.2×10^4 (to the right)

$\therefore 1.2 \times 10^4 = 1200 \times v + 2200 \times 6.5$

$\therefore 12000 = 1200 \times v + 14300$

$\therefore 1200 \times v = -1.917$

$\therefore$ ***v = 1.9 m s^{-1} to the left (ANS)***

2020 Question 10b, 3 marks 64%

Explain, using appropriate physics, why this collision represents an example of either an elastic or an inelastic collision.

If the collision is elastic then the final KE = Initial KE.

Initial KE = $\frac{1}{2} \times 1200 \times 10^2$

$\therefore$ *Initial KE = 60000 J*

$\frac{1}{2} \times 1200 \times 1.9^2 + \frac{1}{2} \times 2200 \times 6.5^2$

$\therefore$ *Final KE = 2166 + 46475*

$\therefore$ *Final KE = 48641 J*

Final KE < Initial KE

$\therefore$ *collision is inelastic.*

2020 Question 10c i, 3 marks 58%

The collision between the car and the van takes 40 ms.

Calculate the magnitude and indicate the direction of the average force on the van by the car.

Use $F\Delta t = m\Delta v$

$\therefore F \times 40 \times 10^{-3} = 2200 \times 6.5$

$\therefore F = 357\ 500$

$\therefore$ ***F = 360 kN to the right.***

(Your answer must be in kN)

2020 Question 10c ii, 2 marks 69%

Calculate the magnitude and indicate the direction of the average force on the car by the van.

The average force on the car is equal but in the opposite direction.

$\therefore$ ***F = 360 kN to the left.***

Question 7 (10 marks)

Kym and Kelly are experimenting with trolleys on a ramp inclined at 25°, as shown in Figure 7. They release a trolley with a mass of 2.0 kg from the top of the ramp. The trolley moves down the ramp, through two light gates and onto a horizontal, frictionless surface. Kym and Kelly calculate the acceleration of the trolley to be 3.2 m s^{-2} using the information from the light gates.

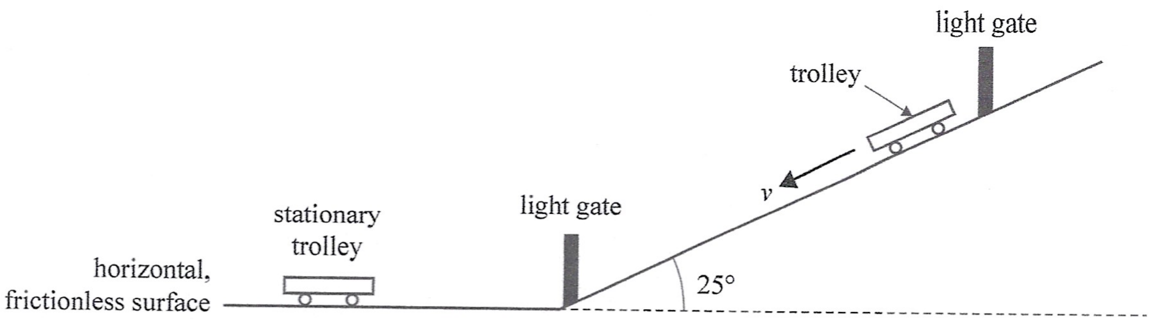


Figure 7

a. **i.** Show that the component of the gravitational force of the trolley down the slope is 8.3 N. Use $g = 9.8$ m s^{-2}. 2 marks

77%

$F = mg \sin\theta$

$= 2 \times 9.8 \sin 25°$

$= 8.3\ N$

ii. Assume that on the ramp there is a constant frictional force acting on the trolley and opposing its motion.

Calculate the magnitude of the constant frictional force acting on the trolley. 2 marks

52%

$mg \sin\theta - F_{fr} = ma$

$8.3 - F_{fr} = 2 \times 3.2$

$F_{fr} = 8.3 - 6.4$

$= 1.9\ N$

1.9	N

b. When it reaches the bottom of the ramp, the trolley travels along the horizontal, frictionless surface at a speed of 4.0 m s^{-1} until it collides with a stationary identical trolley. The two trolleys stick together and continue in the same direction as the first trolley.

i. Calculate the speed of the two trolleys after the collision. Show your working and clearly state the physics principle that you have used. 3 marks

47%

$p_0 = 2 \times 4 = 8$ Ns

$p = 4v$

$4v = 8$

$v = 2$ m s^{-1}

2 m s^{-1}

ii. Determine, with calculations, whether this collision is an elastic or inelastic collision. Show your working. 3 marks

61%

$E_{K_0} = \frac{2 \times 4^2}{2} = 16$ J

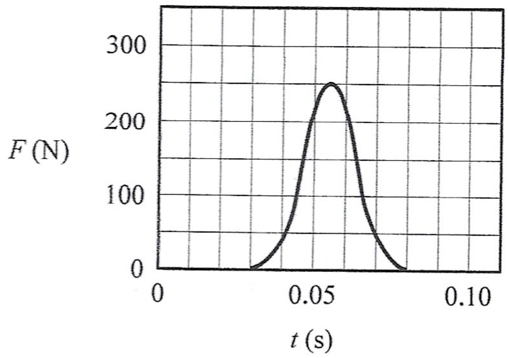
$E_K = \frac{4 \times 2^2}{2} = 8$ J

$E_K < E_{K0}$

Inelastic

Question 4

The diagram below shows the force versus time graph of the force on a tennis ball when it is hit by a tennis racquet. The tennis ball is stationary when the tennis racquet first comes into contact with the ball.



Which one of the following is closest to the impulse experienced by the tennis ball as it is hit by the tennis racquet?

A. 0.50 N s

B. 5.0 N s

C. 10 N s

D. 50 N s

1 sq. 50×0.01 = 0.5 Ns

10 squares