cases is the time during which the loss of energy and momentum occur. Unrestrained, the time to stop will be very short and the deceleration will therefore be very large. A large deceleration means a large force and it is the magnitude of the force that determines the amount of damage.

Seat belts and air bags dramatically increase the time taken by the occupants of the car to stop and as *force* × *time* = *momentum change*, for a constant change in momentum, a long stopping time will imply a smaller, and less damaging, force.

Momentum and sport

This sub-topic began with a suggestion that it was less painful to catch a table-tennis ball than a baseball. You should now be able to understand the reason for the difference. You should also realize why good technique in many sports hinges on the application of momentum change.

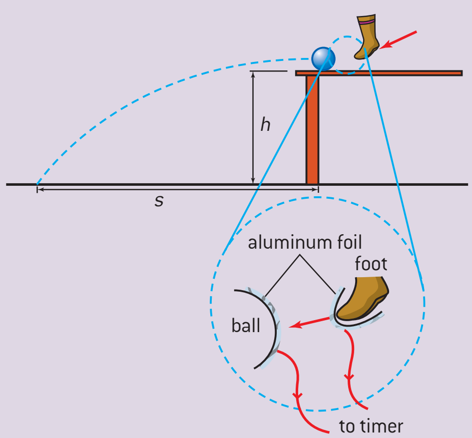
Many sports in which an object – usually a ball – is struck by hand, foot or bat rely on the efficient transfer of momentum. This transfer is often enhanced by a "follow through", which increases the contact time between bat and ball. The player maintains the same force but for a longer time, so the impulse on the ball will increase, increasing the momentum change as well.

Think about your sport and how effective use of momentum change can help you.

Investigate!

Estimating the force on a soccer ball

This experiment will allow you to estimate the force used to kick a soccer ball. It uses many of the ideas contained in this topic and is a good place to conclude our look at IB mechanics!

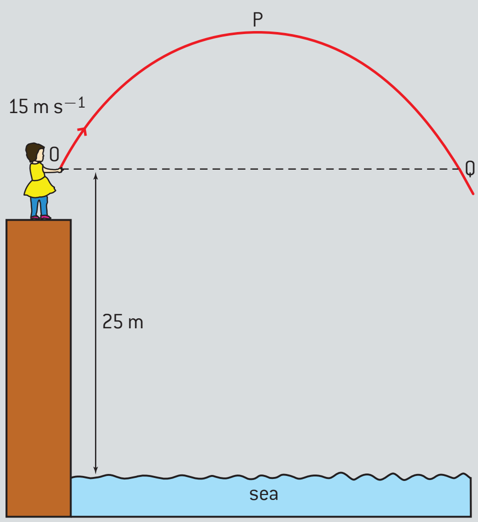


- The basis of the method is to measure the contact time between the foot and the ball and the subsequent change in momentum of the ball. The use of *force* × *contact time* = *change in momentum* allows the force to be calculated.
- To measure the contact time: stick some aluminium foil to the shoe of the kicker and to the soccer ball. Set up a data logger or fast-timer so that it will measure the time T for which the two pieces of foil are in contact.
- To measure the change in momentum: the ball starts from rest so all you need is the magnitude of the final momentum. Get the kicker to kick the ball horizontally from a lab bench. Measure the distance s from where the ball is kicked to where it lands. Measure the distance h from the bottom of the ball on the bench to the floor. Use the ideas of projectile motion to calculate (i) the time t taken for the ball to reach the floor $\left[h = \frac{1}{2}gt^2 \text{ and so } t = \sqrt{\frac{2h}{g}}\right]$. Then using this t, the initial speed u of the ball can be estimated as $\frac{s}{t}$. Measure the mass of the ball M and therefore the change in momentum is Mu which is equal to the *force on the ball* × T.
- This method can be modified for many sports including hockey, baseball, and golf.

Questions

1 *(IB)*

Christina stands close to the edge of a vertical cliff and throws a stone at 15 m s^{-1} at an angle of 45° to the horizontal. Air resistance is negligible.



Point P on the diagram is the highest point reached by the stone and point Q is at the same height above sea level as point O. Christina's hand is at a height of 25 m above sea level.

a) At point P on a copy of the diagram above draw arrows to represent:

(i) the acceleration of the stone (label this A)

(ii) the velocity of the stone (label this V).

b) Determine the speed with which the stone hits the sea. (8 marks)

2 *(IB)*

Antonia stands at the edge of a vertical cliff and throws a stone vertically upwards.

The stone leaves Antonia's hand with a speed $v = 8.0$ m s^{-1}. The time between the stone leaving Antonia's hand and hitting the sea is 3.0 s. Assume air resistance is negligible.

a) Calculate:

(i) the maximum height reached by the stone

(ii) the time taken by the stone to reach its maximum height.

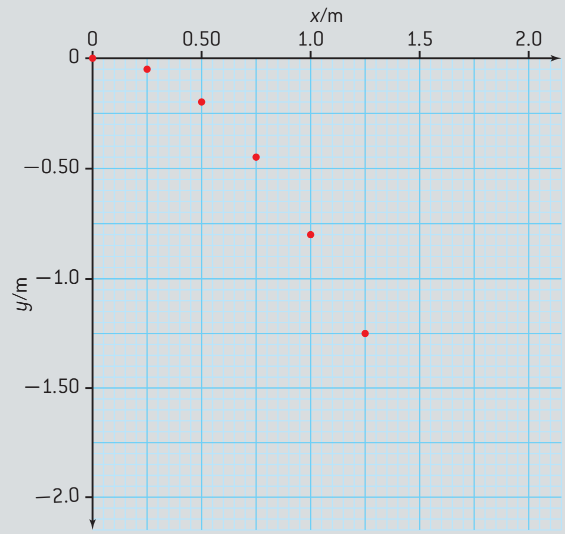
b) Determine the height of the cliff. (6 marks)

3 *(IB)*

A marble is projected horizontally from the edge of a wall 1.8 m high with an initial speed *V*.

A series of flash photographs are taken of the marble and combined as shown below. The images of the marble are superimposed on a grid that shows the horizontal distance *x* and vertical distance *y* travelled by the marble.

The time interval between each image of the marble is 0.10 s.



Use data from the photograph to calculate a value of the acceleration of free fall. (3 marks)

4 *(IB)*

A cyclist and his bicycle travel at a constant velocity along a horizontal road.

a) (i) State the value of the resultant force acting on the cyclist.

(ii) Copy the diagram and draw labelled arrows to represent the vertical forces acting on the bicycle.

(iii) Explain why the cyclist and bicycle are travelling at constant velocity.

b) The total mass of the cyclist and bicycle is 70 kg and the total resistive force acting on them is 40 N. The initial speed of the cycle is 8.0 m s^{-1}. The cyclist stops pedalling and the bicycle comes to rest.

(i) Calculate the magnitude of the initial acceleration of the bicycle and rider.

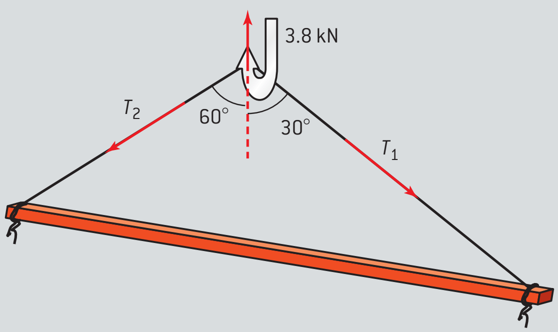
(ii) Estimate the distance taken by the bicycle to come to rest from the time the cyclist stops pedalling.

(iii) State and explain *one* reason why your answer to b)(ii) is an estimate.

(13 marks)

5 A car of mass 1000 kg accelerates on a straight flat horizontal road with an acceleration $a = 0.30$ m s^{-2}. The driving force T on the car is opposed by a resistive force of 500 N. Calculate T. (3 marks)

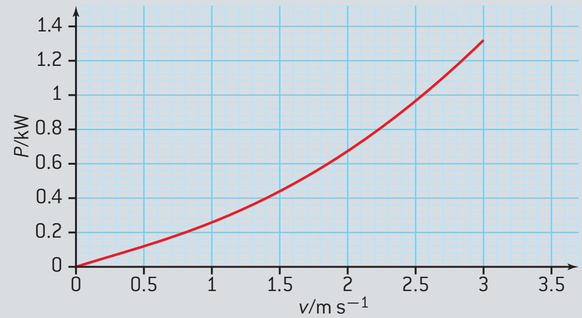
6 A crane hook is in equilibrium under the action of three forces as shown in the diagram.



Calculate T_1 and T_2. (4 marks)

7 *(IB)*

A small boat is powered by an outboard motor of variable power P. The graph below shows the variation with speed v of the power P for a particular load.



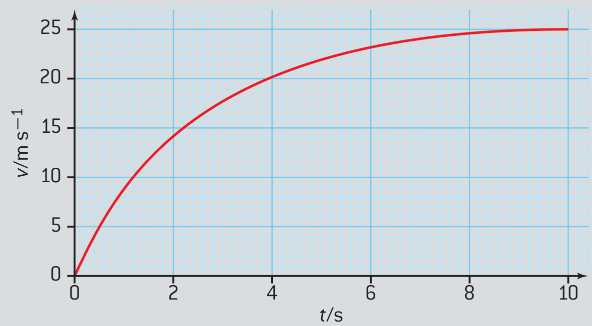
For a steady speed of 2.0 m s^{-1}:

a) use the graph to determine the power of the boat's engine

b) calculate the frictional (resistive) force acting on the boat. (3 marks)

8 *(IB)*

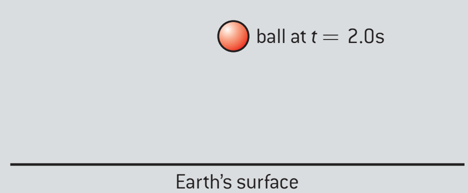
The graph shows the variation with time t of the speed v of a ball of mass 0.50 kg that has been released from rest above the Earth's surface.



The force of air resistance is *not* negligible.

a) State, without any calculations, how the graph could be used to determine the distance fallen.

b) (i) Copy the diagram and draw and label arrows to represent the forces on the ball at 2.0 s.



(ii) Use the graph to show that the acceleration of the ball at 2.0 s is approximately 4 m s^{-2}.

(iii) Calculate the magnitude of the force of air resistance on the ball at 2.0 s.

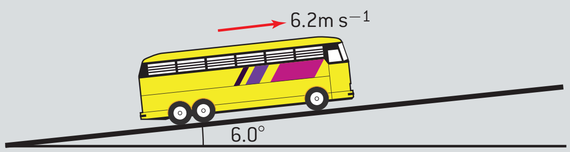
(iv) State and explain whether the air resistance on the ball at $t = 5.0$ s is smaller than, equal to, or greater than the air resistance at $t = 2.0$ s.

c) After 10 s the ball has fallen 190 m.

(i) Show that the sum of the potential and kinetic energies of the ball has decreased by about 800 J. (14 marks)

9 *(IB)*

A bus is travelling at a constant speed of 6.2 m s^{-1} along a section of road that is inclined at an angle of 6.0° to the horizontal.



a) (i) Draw a labelled sketch to represent the forces acting on the bus.

(ii) State the value of net force acting on the bus.

b) The total output power of the engine of the bus is 70 kW and the efficiency of the engine is 35%.

Calculate the input power to the engine.

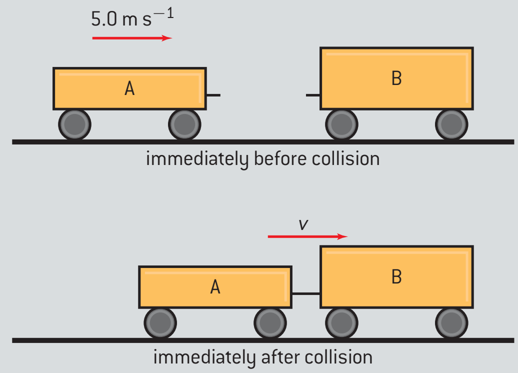
c) The mass of the bus is 8.5×10^3 kg.

Determine the rate of increase of gravitational potential energy of the bus.

d) Using your answer to c (and the data in b), estimate the magnitude of the resistive forces acting on the bus. (12 marks)

10 *(IB)*

Railway truck A moves along a horizontal track and collides with a stationary truck B. The two join together in the collision. Immediately before the collision, truck A has a speed of 5.0 m s^{-1}. Immediately after collision, the speed of the trucks is v.



The mass of truck A is 800 kg and the mass of truck B is 1200 kg.

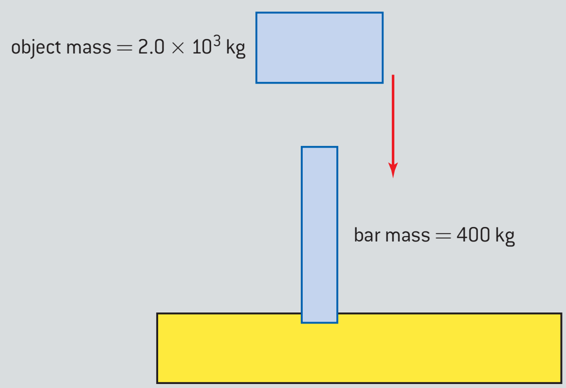
a) (i) Calculate v.

(ii) Calculate the total kinetic energy lost during the collision.

b) Suggest where the lost kinetic energy has gone. (6 marks)

11 *(IB)*

Large metal bars are driven into the ground using a heavy falling object.



The falling object has a mass 2000 kg and the metal bar has a mass of 400 kg.

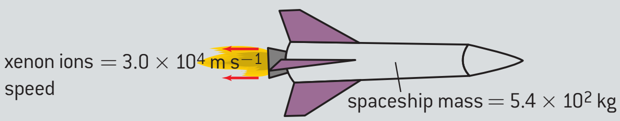
The object strikes the bar at a speed of 6.0 m s^{-1}. It comes to rest on the bar without bouncing. As a result of the collision, the bar is driven into the ground to a depth of 0.75 m.

a) Determine the speed of the bar immediately after the object strikes it.

b) Determine the average frictional force exerted by the ground on the bar. (7 marks)

12 *(IB)*

An engine for a spacecraft uses solar power to ionize and then accelerate atoms of xenon. After acceleration, the ions are ejected from the spaceship with a speed of $3.0 \times 10^4\, m\, s^{-1}$.

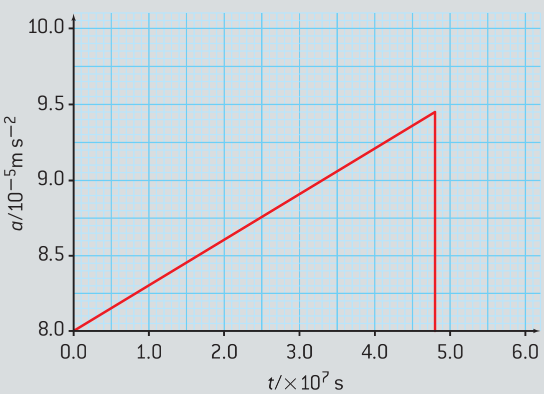


The mass of one ion of xenon is 2.2×10^{-25} kg

a) The original mass of the fuel is 81 kg. Determine how long the fuel will last if the engine ejects 77×10^{18} xenon ions every second.

b) The mass of the spaceship is 5.4×10^2 kg. Determine the initial acceleration of the spaceship.

The graph below shows the variation with time t of the acceleration a of the spaceship. The solar propulsion engine is switched on at time $t = 0$ when the speed of the spaceship is 1.2×10^3 m s^{-1}.

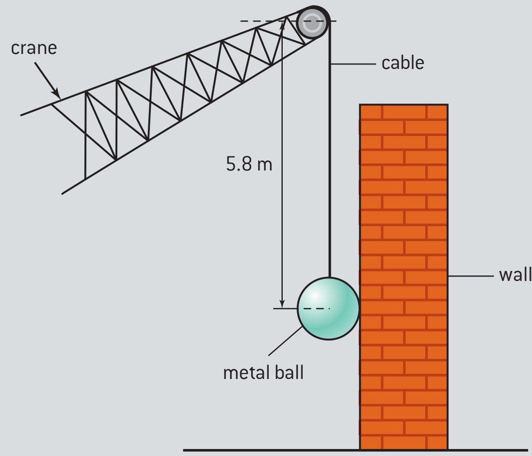


c) Explain why the acceleration of the spaceship increases with time.

d) Using data from the graph, calculate the speed of the spaceship at the time when the xenon fuel has all been used. (15 marks)

13 *(IB)*

A large metal ball is hung from a crane by means of a cable of length 5.8 m as shown below.



To knock a wall down, the metal ball of mass 350 kg is pulled away from the wall and then released. The crane does not move. The graph below shows the variation with time t of the speed v of the ball after release.

The ball makes contact with the wall when the cable from the crane is vertical.

a) For the ball just before it hits the wall use the graph, to estimate the tension in the cable. The acceleration of free fall is $9.8\, m\, s^{-2}$.

b) Determine the distance moved by the ball after coming into contact with the wall.

c) Calculate the total change in momentum of the ball during the collision of the ball with the wall. (7 marks)