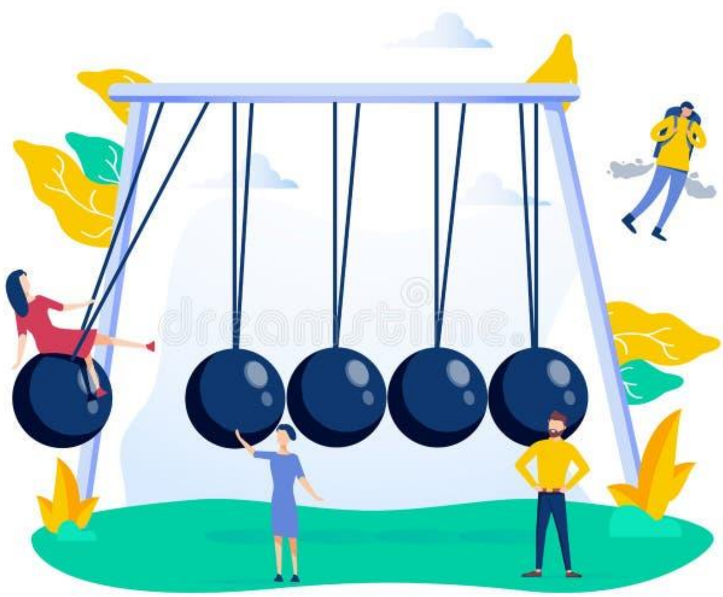
Edexcel AS

Physics

(Code: WPH11)

Topic 01
Mechanics



1A Motion

1A.1 Velocity and acceleration

Rate of movement

$$s = \frac{d}{t}$$

$$v = \frac{\Delta s}{\Delta t}$$

Acceleration

$$a = \frac{\Delta v}{\Delta t}$$

1A.2 Motion graphs

Displacement-time graph

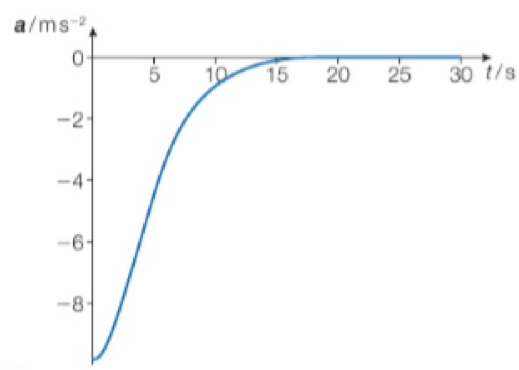
- Gradient gives the velocity (speed if it's a distance-time graph).

Velocity-time graph

- Gradient gives acceleration.
- Area under the graph gives the displacement travelled.

Acceleration-time graph

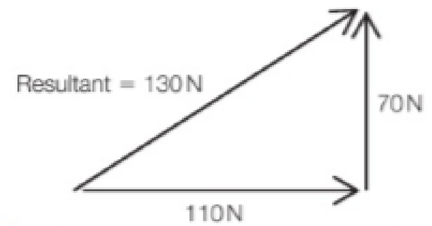
- In many instances the acceleration is zero or a constant value, in which case an acceleration-time graph is likely to be of relatively little interest.
- The graph shows the acceleration of a skydiver; For a larger object falling for a long period, such as a skydiver, then the acceleration will change over time as the air resistance increases with speed. The weight of a skydiver is constant, so the resultant force will be decreasing throughout, which means that the acceleration will also reduce.



1A.3 Adding forces

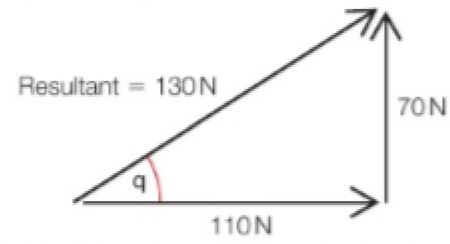
Adding perpendicular forces

Magnitude

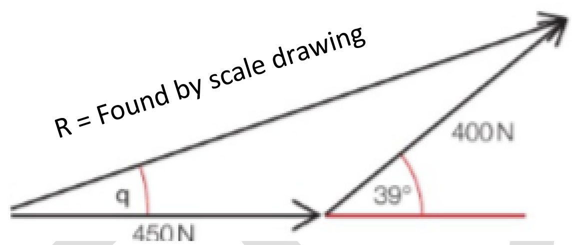


We can draw them, one after the other, as the two sides of a right-angled triangle and use Pythagoras' theorem to calculate the size of the hypotenuse.

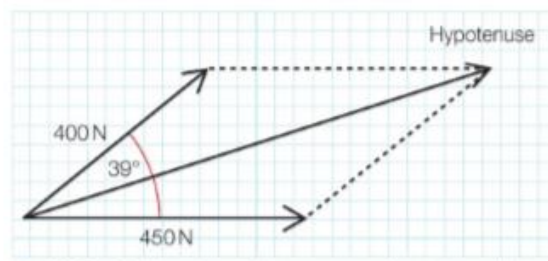
Direction



Adding two non-perpendicular forces



or

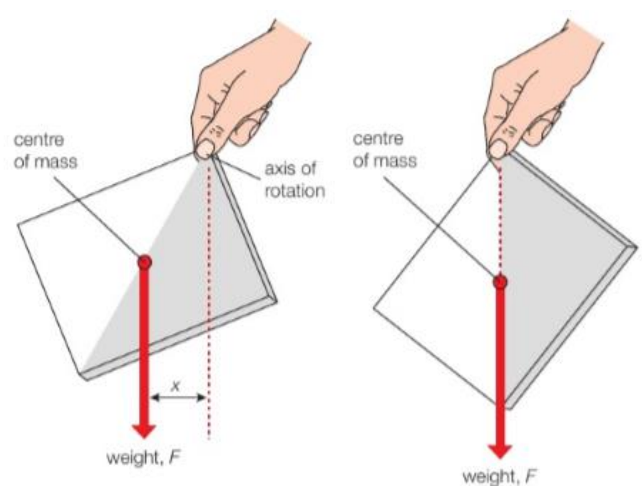


1A.4 Moments

The moment of a force

The tendency to cause rotation is called the moment of force.

$$\boxed{moment = fx}$$



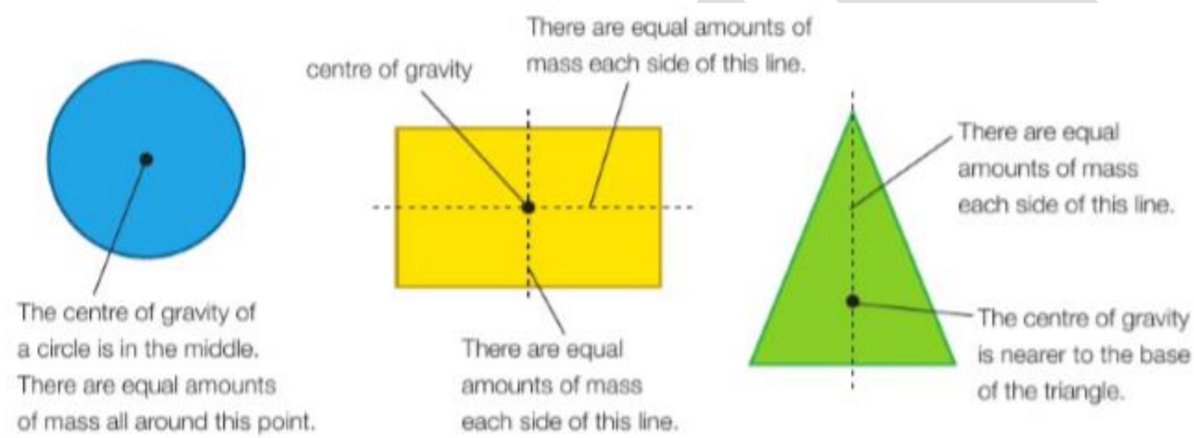
The principle of moments

When we add up all the forces acting on an object and the resultant force, accounting for their directions, is zero, then the object will be in *equilibrium*.

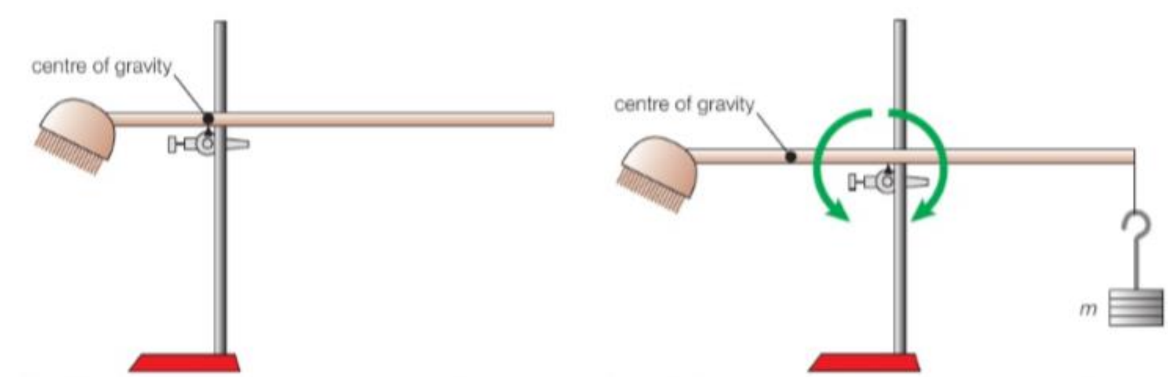
The *principle of moments* tells us that if the total of all the moments trying to turn an object clockwise is equal to the total of all moments trying to turn an object anticlockwise, then it will be in *rotational equilibrium*. This means it will either remain stationary, or if it is already rotating it will continue at the same speed in the same direction.

Centre of gravity

The sum of all the tiny weight forces appears to act from a single point for any object, and this point is called the centre of gravity.



Irregular objects



1A.5 Newton's laws of motion

Newton's first law

An object at rest remains at rest, and an object in motion remains in motion at constant speed and in a straight line unless acted on by an unbalanced force.

Newton's second law

The rate of change of momentum of a body is directly proportional to the resultant force applied to the body, and is in the same direction as the force.

$$\boxed{f = ma}$$

Newton's third law

For every action (force) in nature there is an equal and opposite reaction.

1A.6 Kinematic equations

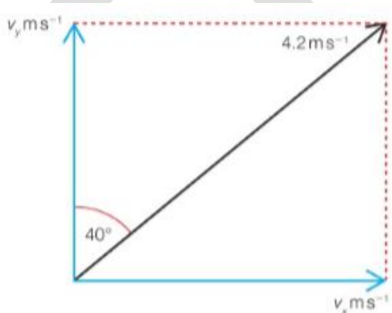
Kinematics is the study of the movement of object.

KINEMATICS EQUATION	QUANTITY NOT USED
$v = u + at$	distance
$s = \frac{(u + v)}{2} \times t$	acceleration
$s = ut + \frac{1}{2}at^2$	final velocity
$v^2 = u^2 + 2as$	time

s – displacement (m)
u – initial velocity ($m\,s^{-1}$)
v – final velocity ($m\,s^{-1}$)
a – acceleration ($m\,s^{-2}$)
t – time (s)

1A.7 Resolving vectors

Resolving vectors calculations



Vertical component

$$\cos 40° = \frac{v_y}{4.2}$$

Horizontal component

$$\sin 40° = \frac{v_x}{4.2}$$

LEARNING TIP

sin $\theta°$ = opposite/hypotenuse

cos $\theta°$ = adjacent/hypotenuse

tan $\theta°$ = opposite/adjacent

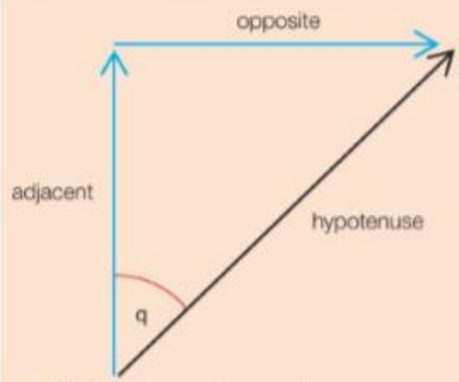
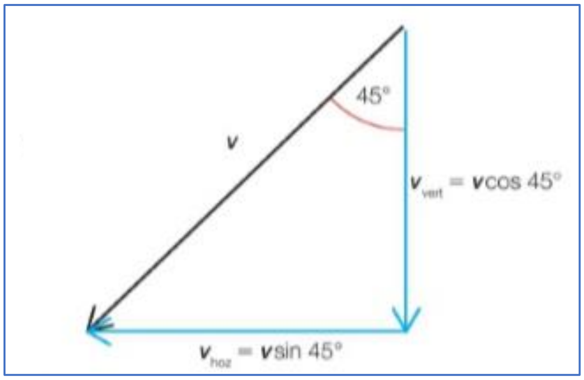
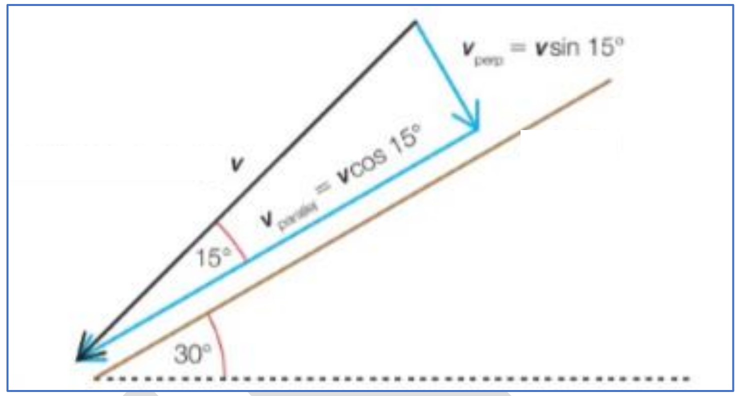


fig D rigonometry reminder.

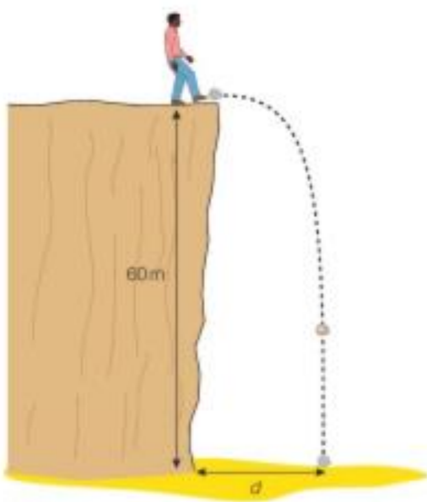
Alternative resolution angles





1A.8 Projectiles

Horizontal throws



The time to hit the beach, t, will be the same as if the stone was simply dropped. We know $\boldsymbol{u} = 0\,\text{m s}^{-1}$; $\boldsymbol{a} = -9.81\,\text{m s}^{-2}$; and the height fallen, $\boldsymbol{s} = -60\,\text{m}$.

$$s = ut + \tfrac{1}{2}at^2$$

$$u = 0 \therefore ut = 0$$

$$\therefore \quad s = \tfrac{1}{2}at^2$$

$$\therefore \quad t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{(2 \times -60)}{-9.81}}$$

$$t = 3.5\,\text{s}$$

Horizontally, there is no accelerating force once the stone is in flight, so it has a constant speed. Thus, to find the distance travelled horizontally, $\boldsymbol{d}$:

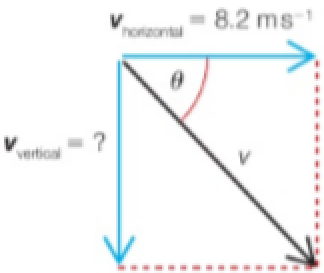
$$v = \frac{d}{t}$$

$$\therefore \quad d = v \times t$$

$$d = 8.2 \times 3.5$$

$$d = 28.7\,\text{m}$$

Recombining velocity components



The horizontal velocity was given as 8.2 m s^{-1}. To calculate the vertical velocity: $u = 0$ m s^{-1}; $a = -9.81$ m s^{-2}; and $s = -60$ m.

$$v^2_{vertical} = u^2 + 2as = 0^2 + (2 \times -9.81 \times -60) = 1177.2$$

$$\therefore \quad v_{vertical} = \sqrt{1177.2} = -34.3$$

$$v_{vertical} = -34.3 \text{ m s}^{-1}$$

Pythagoras' theorem gives the magnitude of the final velocity:

$$v = \sqrt{(8.2^2 + 34.3^2)}$$

$$\therefore \quad v = 35.3 \text{ m s}^{-1}$$

Trigonometry will give the angle at which the stone is flying on impact with the beach:

$$\tan\theta = \frac{34.3}{8.2}$$

$$\therefore \quad \theta = 77°$$

The stone's velocity when it lands on the beach is 35.3 metres per second at an angle of 77° down from the horizontal.

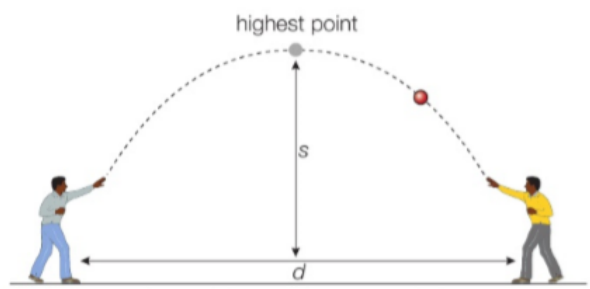
Vertical throw

Consider the second question first: uniform acceleration under gravity means $a = -9.81$ m s^{-2} and the kinematics equations can be used. We know $u = 5.5$ m s^{-1}; at the top of the path, $v = 0$ m s^{-1}; and we want to find the height, s.

$$v^2 = u^2 + 2as$$

$$\therefore \quad s = \frac{v^2 - u^2}{2a} = \frac{0^2 - (5.5)^2}{2 \times -9.81}$$

$$s = 1.54 \text{ m}$$



Note that 1.54 metres is actually the height the ball reaches above the point of release at which it left the hand – the point where its initial speed was 5.5 m s^{-1} – but this is often ignored in projectiles calculations.

The time of flight for the ball will be just the time taken to rise and fall vertically. We find the time to reach the highest point, and then double that value. We know $u = 5.5$ m s^{-1}; at the top of the path, $v = 0$ m s^{-1}; and we want to find the time, t.

$$v = u + at$$

$$\therefore \quad t = \frac{v - u}{a} = \frac{0 - (5.5)}{-9.81}$$

$$t = 0.56 \text{ s}$$

So the overall time of flight will be 0.56 seconds doubled: total time = 1.12 s.

1B Energy

1B.1 Gravitational potential and kinetic energy

Gravitational potential energy

$$\Delta E_{grav} = mgh$$

Kinetic energy

$$E_k = \frac{1}{2} \times m \times v^2$$

Transfer between E_{grv} and E_k

$$\Delta E_{grv} = mg\Delta h = \frac{1}{2}mv^2 = E_k$$

$$v = \sqrt{2g\Delta h}$$

$$\Delta h = \frac{v^2}{2g}$$

1B.2 Work and Power

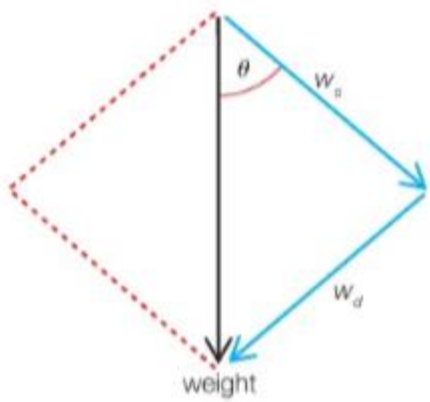
The law of *conservation of energy* states that the total amount of energy in an isolated system remains constant over time.

Work

The amount of work done means the amount of energy transferred, so work is measured in joules.

$$\Delta W = F\Delta s$$

Work done by forces at an angle



The weight component working down the slope equals the friction, F

$F = mgcos\theta$

The work done is force multiplied by the distance travelled along the line of the force, so here:

$work = \Delta s \times mgcos\theta$

The work done when there is an angle between the force and the distance along which we are measuring:

$$\Delta W = F\Delta s cos\theta$$

Power

Power is defined as the rate of energy transfer

$$\boxed{P = \frac{E}{t}} \qquad \boxed{P = \frac{\Delta W}{t}} \qquad \boxed{P = \frac{F\Delta s}{t}}$$

Efficiency

The ability of a machine to transfer energy usefully is called *efficiency*.

$$\boxed{Efficiency = \frac{useful\ work\ done}{total\ energy\ input}} \qquad \boxed{Efficiency = \frac{useful\ energy\ output}{total\ energy\ input/output}}$$

1C Momentum

1C.1Momentum

Momentum is a measure of an object's motion.

$$\boxed{p = m \times v}$$

Newton's second law of motion

$$\boxed{F = \frac{\Delta p}{\Delta t}}$$

1C.2 Conservation of linear momentum

Collision

The law of *conservation of momentum* states that when two objects collide in an isolated system, the total momentum before and after the collision remains equal.

Explosions

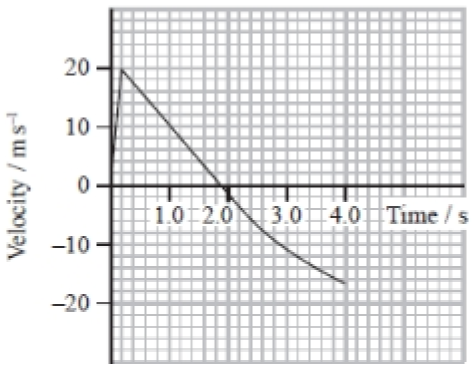
When a stationary object explodes, then the total momentum of all the shrapnel parts added up (taking account of the direction of their movements) must be zero.

Newton's third law

For conservation of momentum, the Earth must gain an equal and opposite momentum. This is then caused by an equal and opposite gravitational force on the Earth from the apple. The huge mass of the Earth means that its acceleration cannot be noticed by us.

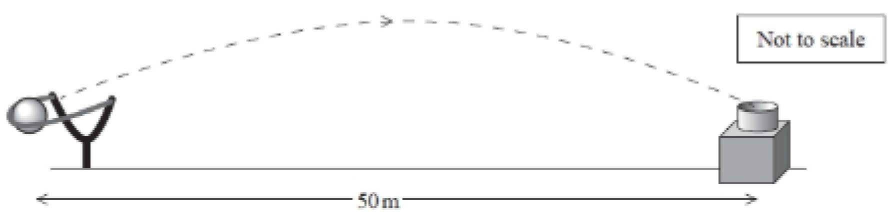
EXCERSISE

1. A physics class made a toy rocket. A drinks bottle was partially filled with water and inverted over a valve. An air pump delivered air to the bottle until the pressure forced the bottle from the valve and the water was ejected from the bottle at high speed.
   A velocity-time graph for the bottle for the first 4 s after take-off is shown.



   Sketch the corresponding acceleration-time graph.

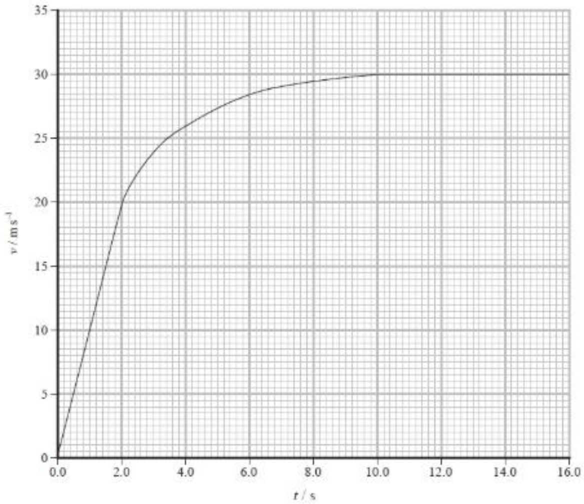
2. A fairground game requires the player to catapult a ball towards a target to score points. The ball is required to reach a target a horizontal distance of 50 m away, at the same vertical height, as shown. The time taken for the ball to reach the target is 2.0 s. Calculate the angle to the horizontal at which the ball is launched.



3. The Shanghai Maglev Train is the first commercially operated high-speed magnetic levitation train in the world, connecting the airport and central Shanghai. The total distance travelled is 29.9 km and the total journey time is 440 s. The train starts from rest and reaches a speed of 97 m s^{-1} in 120 s.

   i. Calculate the average acceleration of the train during the first 120 s.
   ii. Calculate the average speed of the train for the period following the 120 s acceleration.

4. A skydiver made a skydive from a plane. The graph shows how the velocity v of the skydiver varied with time t, from the instant she left the plane to the instant just before the parachute opened.

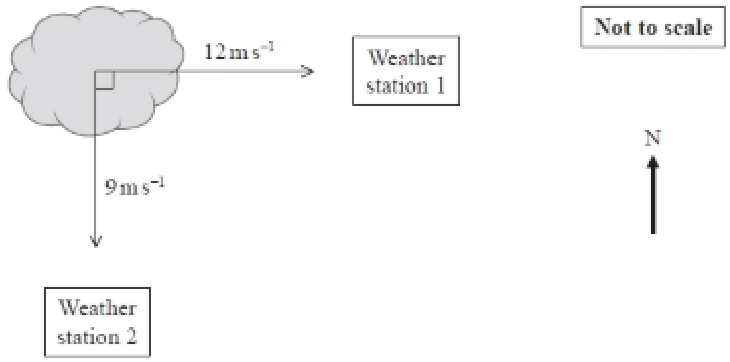


Determine an approximate value for the displacement of the skydiver over the first 16.0 s of the skydive.

5. A motorist received a speeding penalty notice, from the police, for a short journey along 120 m of road.
   a. The car's specification states that the minimum time for the car to accelerate from 0 to 60 miles per hour is 9.5 seconds. Show that the maximum value for the average acceleration of the car over 9.5 s is about 3 m s^{-2}.
   1 mile = 1600 m
   b. The police recorded a maximum speed for the car of 20 m s^{-1}. The motorist knows that the speed at the start and at the end of the 120 m journey was zero.
   Assume that the car had:
      - constant positive acceleration, equal to the value in part (a), for the first 60 m of the journey
      - constant negative acceleration of the same magnitude for the final 60 m of the journey.

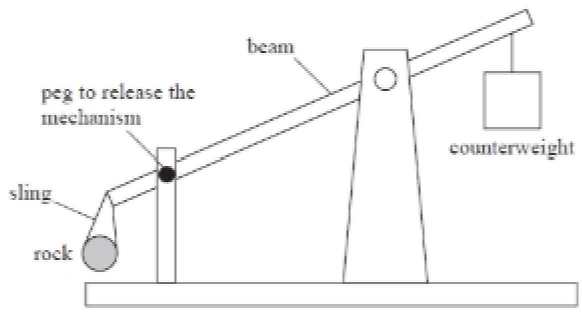
   Determine whether the motorist should challenge the penalty notice.
   c. Explain why the assumptions about the acceleration in (b) may not be correct in practice.

6. Weather stations monitor the position of storm clouds. The movement of a storm cloud is monitored by two weather stations. The components of the velocity of the storm cloud towards each weather station are shown in the diagram.

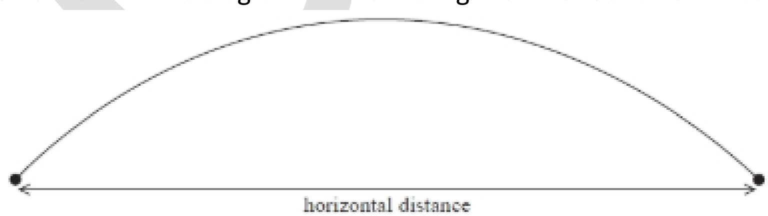


Determine the velocity of the storm cloud.

7. A trebuchet is a medieval catapult designed to project a rock over large distances. A simplified diagram of a trebuchet is shown.

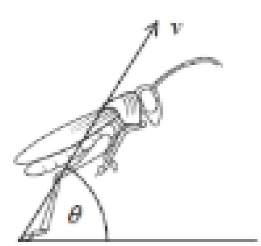


The rock is held in a sling. When the peg is removed the counterweight falls and the rock is projected through the air. The rock was projected with a velocity of 41.5 m s–1 at an angle of 30° to the horizontal. The diagram shows the flight of the rock after it has left the trebuchet.



The rock rises to a maximum height and then falls back to the same height as its release height. Calculate the horizontal distance travelled by the rock in this time.

8. Grasshoppers can jump up to twenty times their length to escape predators. The magnitude of the launch velocity v does not vary significantly for a given grasshopper, so the length of the jump mostly depends on the launch angle θ. The diagram shows a grasshopper at the instant it launches.

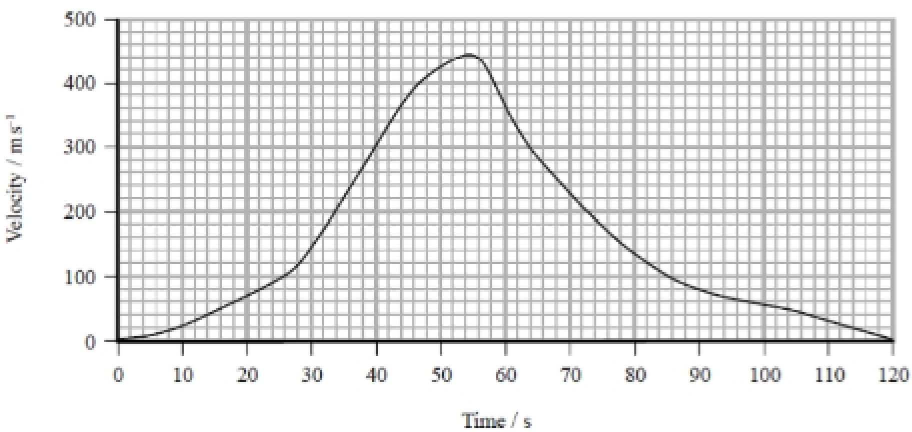


The grasshopper jumps from rest on level ground. The launch velocity is 2.6 m s−1 at an angle of 57° to the horizontal.

i. Show that the vertical component of the launch velocity is about 2 m s^{-1}.

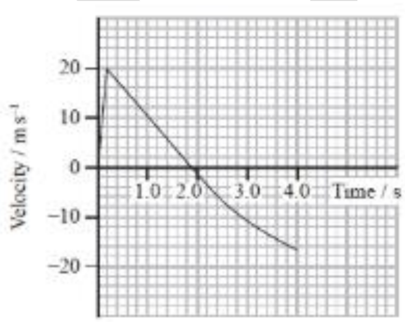
ii. Assess whether the horizontal distance travelled by the grasshopper in the jump is about 20 times the grasshopper's length. length of grasshopper = 5.0 cm

9. The world land speed record of 341 m s^{-1} was set in October 1997. In an attempt to break this record, a new supersonic car has been developed called the Bloodhound. The developers of the Bloodhound have used computer modelling to produce a velocity-time graph for the predicted motion of the car, on a straight track, during the record attempt.



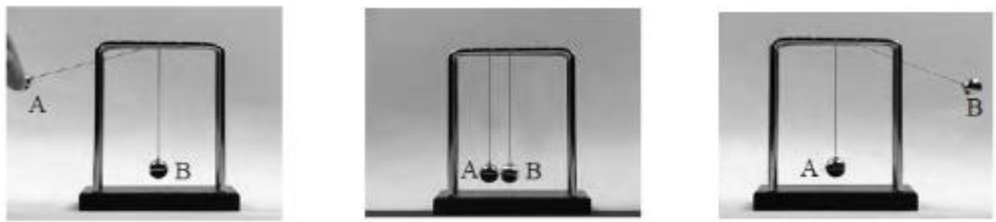
A track of length 23 km is available for the record attempt. Determine whether this track is long enough.

10. A physics class made a toy rocket. A drinks bottle was partially filled with water and inverted over a valve. An air pump delivered air to the bottle until the pressure forced the bottle from the valve and the water was ejected from the bottle at high speed.
A velocity-time graph for the bottle for the first 4 s after take-off is shown.



Determine the height to which the rocket travelled.

11. Two small identical solid metal spheres, A and B, are suspended by light inextensible threads from a frame.
    - Sphere A is pulled to one side as shown and released. Sphere A collides with sphere B and stops and sphere B swings upwards. The time intervals between the photographs below are the same.



Photograph 1 Photograph 2 Photograph 3

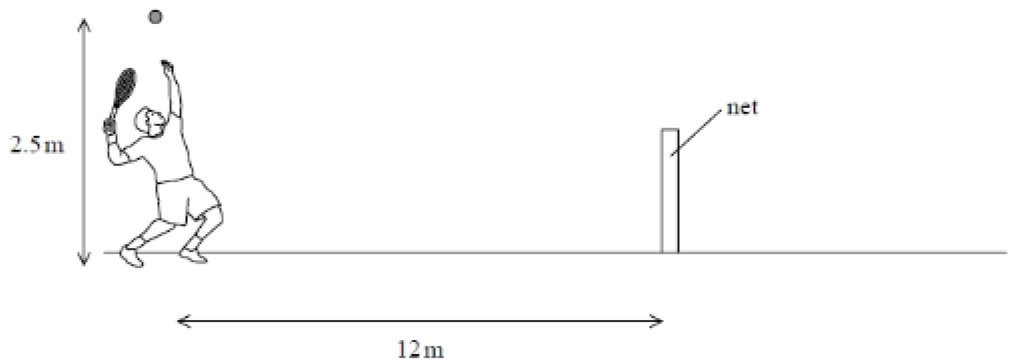
Using Newton's laws of motion, explain the motion of the spheres during the collision in terms of the forces acting on them.

12. Some sports place high stresses on the bones in the body, which can result in injury. A gymnast of mass 45 kg dismounts from a beam. Her centre of mass is displaced through 1.6 m vertically before her feet touch the ground. As she lands, the bones in the lower part of her legs experience a force from the ground. The time between hitting the ground and coming to rest is 0.90 s.
    i. Calculate the mean force from the ground on the gymnast
    ii. Explain how bending both knees when landing helps the gymnast prevent an injury

13. Two ice skaters are gliding across the horizontal ice surface at an ice rink. Initially the skaters move together with a speed of 5.6 m s^{-1}. The male skater pushes the female skater forwards. After being pushed, she has a forward speed of 7.5 m s^{-1}. Calculate the speed of the male skater immediately after pushing the female skater forwards.
    mass of male skater = 66 kg
    mass of female skater = 52 kg

14.
    a. A vehicle that skids can leave a mark on the road surface. This skid mark can be used to calculate the velocity of the vehicle at the start of the skid. At a test track a car of mass 1500 kg was collided into the back of a stationary car of mass 1200 kg. The two cars skidded along the road together, leaving skid marks of length 7.5 m. The cars decelerated at 5.6 m s−2 to a stop at the end of the skid. Calculate the velocity with which the car of mass 1500 kg collided with the stationary car.
    b. In practice, the velocity of the car is not exactly the same as that calculated. Explain why.

15. A tennis player uses a racket to hit a ball over a net

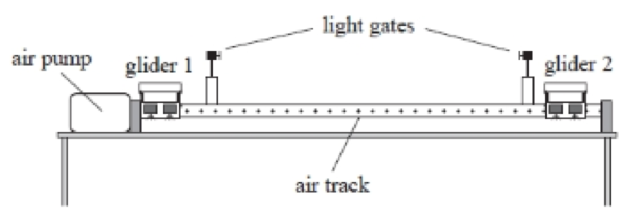


The player stands 12 m from the net. He throws the ball vertically upwards and hits the ball at a height of 2.5 m above the ground. The ball leaves the racket horizontally with a velocity of 25 m s^{-1}. The ball has a mass of 0.06 kg. The ball is in contact with the racket for 0.04 s. Calculate the average force on the ball.

16. A website about the physics of baseball states, "The bat hits the ball with a force equivalent to 2 tonnes."
In a baseball game, a ball travelling at 40 ms^{-1} is in contact with a bat for 0.70 ms and has a speed after impact of 49 ms^{-1}.
1 tonne = 1000 kg
mass of ball = 0.15kg
Evaluate the statement from the website.

17. A uniform paving slab is to be used as a garden step. State what is meant by the centre of gravity of an extended body

18. A teacher uses a linear air track to provide a frictionless surface for two gliders, each of mass m. She uses this, with a pair of light gates connected to a computer, to investigate a collision between the gliders. The gliders are each given a small push and travel towards the centre of the track. The gliders collide and move off together.

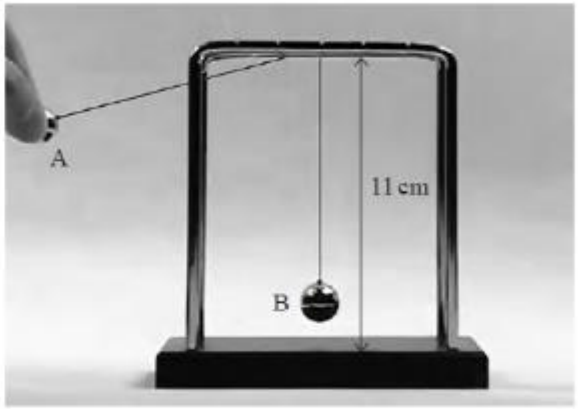


The teacher asked a student to justify the change in velocity of glider 1 using Newton's laws of motion.
The student began his explanation with the statement:

"During the collision there is a force on glide 2"

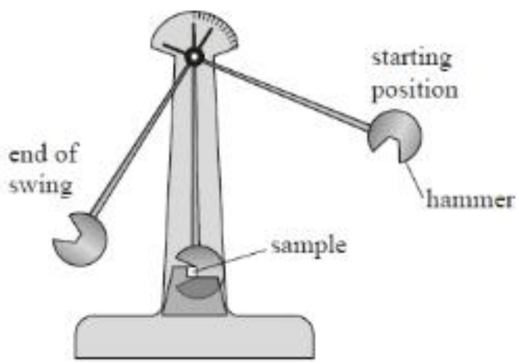
Complete the explanation to justify the change in velocity of glider 1, making reference to Newton's laws of motion where appropriate.

19. Two small identical solid metal spheres, A and B, are suspended by light inextensible threads from a frame. The photograph shows sphere A just before it was released.



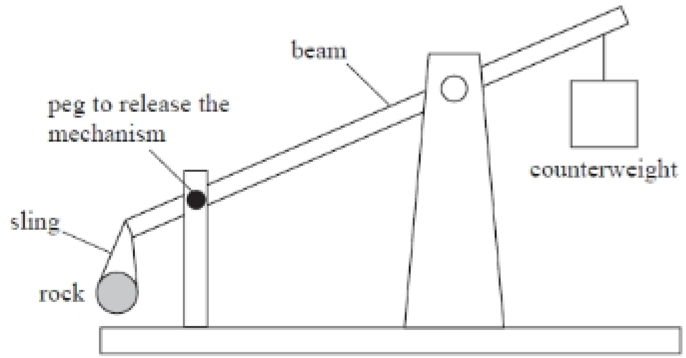
Determine the momentum of sphere A just before the collision. You should take measurements from the photograph.
Height of frame = 11 cm
Mass of sphere = 0.022 kg

20. Read the passage and answer the questions below



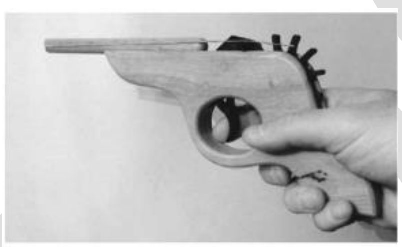
The Charpy test is used by scientists to measure the fracture toughness of a material. A simple pendulum, with a hammer on the end, is held high and released so that it swings down and strikes the sample. The height from which the hammer is released is increased until the sample fractures. Some energy is absorbed by the sample in the impact but the hammer continues to move until it comes to rest at the top of its swing. Due to the law of conservation of energy the hammer will not swing up as high as its starting position. The difference in height between the start and end is proportional to the energy absorbed in the impact – the fracture toughness.
The hammer is released from a height of 13.0 cm above the lowest point of the swing.
Calculate the momentum of the hammer when it strikes the sample.
mass of hammer = 31 kg

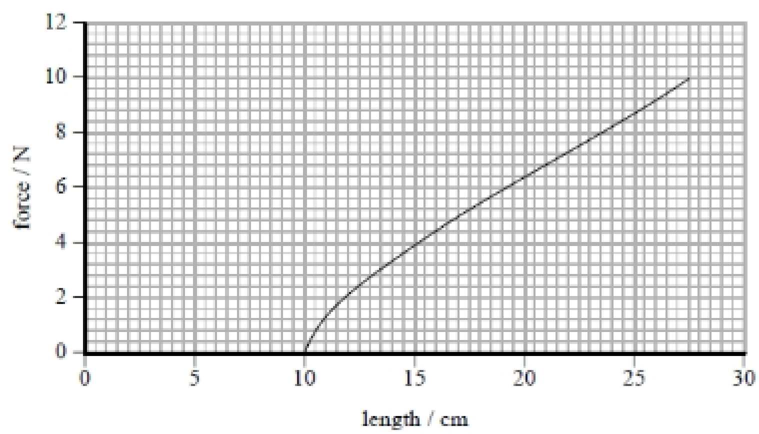
21. A trebuchet is a medieval catapult designed to project a rock over large distances. A simplified diagram of a trebuchet is shown.



The rock is held in a sling. When the peg is removed the counterweight falls and the rock is projected through the air. The mass of the counterweight was reduced. The trebuchet was then used to project the rock again. Explain why the horizontal distance travelled by the rock decreases.

22. The photograph shows a toy that fires rubber bands.
A student investigates the properties of one of the rubber bands and obtains the following graph.

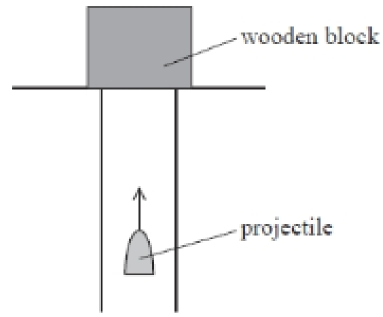




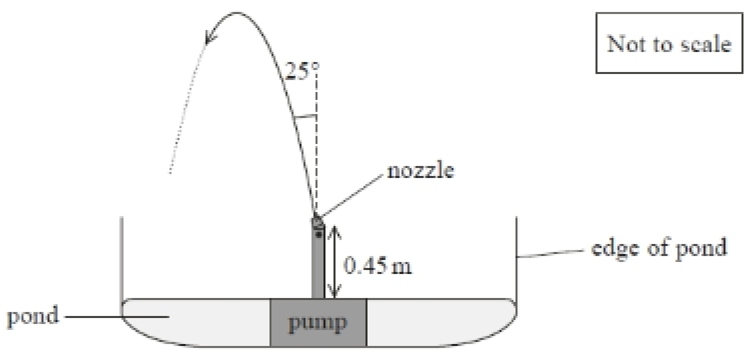
a. The student wants to determine the mass of one of the rubber bands. He places five rubber bands on a balance and obtains a reading of 2 g. He divides the reading on the balance by five to determine the mass of one rubber band. Explain how he could improve his result.
b. The rubber band is stretched by 17.4 cm when it is placed on the toy. Show that the work done on the rubber band is about 1 J.
c. Calculate the maximum possible value for the initial velocity of the rubber band as it is fired from the toy. Assume the mass of a rubber band is 0.4 g.

d. The student thinks the calculated value of maximum velocity is too high because the band does not travel as far as expected. Explain how the student could determine the initial velocity with the use of a video camera and why light gates would not be suitable.

23. A projectile of mass 65 g is fired vertically upwards into a stationary wooden block of mass 2.400 kg, as shown. The projectile becomes embedded in the block. They both move vertically upwards through a vertical displacement of 55 cm before momentarily coming to rest. Calculate the energy dissipated as the projectile hits the block.

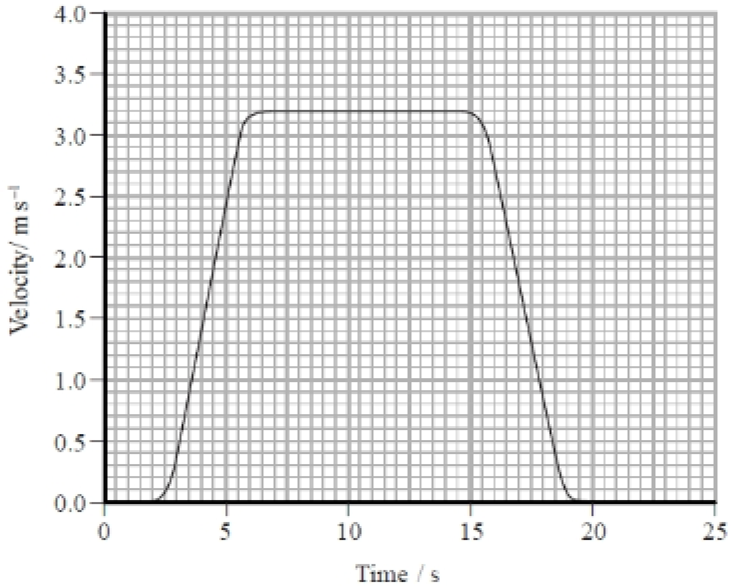


24. A garden pond contains a water fountain. The fountain consists of a pump and nozzle and is used to create a jet of water which falls back into the pond as shown. The top of the edge of the pond is level with the nozzle.



The water is lifted through a height of 0.45 m before it leaves the nozzle at an angle of 25° to the vertical.
The efficiency of the pump is 76 %.
Show that the water leaves the nozzle at a speed of about 8 m s^{-1}.
Mass of water leaving the pump each second = 3.5 kg s^{-1}
Power of pump = 160 W

25. A lift moves upwards from the ground to the tenth floor of a building. The velocity-time graph for the lift is shown.



The power developed by the lift when travelling upwards with different loads is shown in the table.

Number of passengers	Load / kg	Power developed when accelerating / kW	Power developed when at constant velocity / kW
0	0	34	25
1	75	39	28
2	150	44	31
3	225	49	34

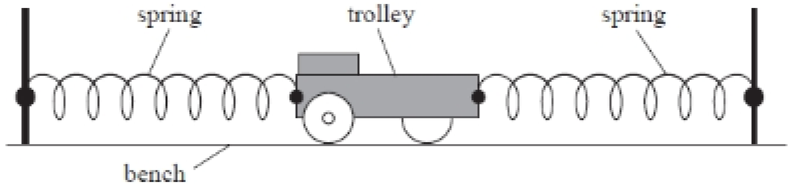
i. By considering the forces acting on the lift as it rises, discuss the difference in values for the power developed by the lift.

ii. Lifts use a significant proportion of all total energy consumption of a building. When designing the lift systems, engineers compare the predicted daily energy consumption of different lift motors by

- estimating the time for typical lift journey based on the number of floors in the building and the speed of the lift
- estimating the number of lift journeys per day using daily energy consumption = maximum power output of motor × number of journeys × time per journey

Discuss the advantages and disadvantages of using this method to compare the predicted energy consumption of different lift motors.

26. A trolley is attached to the ends of two springs as shown. When displaced from its equilibrium position, the trolley moves with simple harmonic motion.



The student displaces the trolley a greater distance from the equilibrium position, so the amplitude of oscillation is doubled. The trolley still moves with simple harmonic motion. Explain how the maximum kinetic energy of the trolley will change.

27. Seat belts are being tested by a car manufacturer. In the test, a car moving at a steady speed of 28 m s^{-1} collides with a wall and stops.
A crash-test dummy in the driving seat is wearing a seat belt made from polyester webbing. The seat belt has a cross-sectional area of 0.85 cm^2 and a total length of 2.0 m. A student suggests that in the collision the seat belt absorbs all the kinetic energy of the dummy.
Show that the energy per unit volume that would have to be absorbed by the seat belt is about 2 × 108 J m^{-3}.
Mass of dummy = 75 kg

28. Read the extract and answer the question that follows. Gravitricity is developing a new technology to capture and store the excess power generated by renewable energy resources. A large load is suspended by cables in a disused mineshaft. During periods of low power demand, excess generated power is used to winch the load upwards. During periods of high demand, the load is lowered down the shaft, causing electricity to be generated. The system can produce electricity at low power for several hours, or a short burst of electricity at high power. One such system is planned to use a load of mass 2500 tonnes. The load will be at the top of a shaft. The load will be lowered down the shaft at a steady speed. A useful power output of 15MW will be generated. The system will have an efficiency of 80%. The system can generate "a short burst of electricity at high power". Explain why high power can be generated for only a short time.

29. Read the extract and answer the question that follows. Gravitricity is developing a new technology to capture and store the excess power generated by renewable energy resources. A large load is suspended by cables in a disused mineshaft. During periods of low power demand, excess generated power is used to winch the load upwards. During periods of high demand, the load is lowered down the shaft, causing electricity to be generated. The system can produce electricity at low power for several hours, or a short burst of electricity at high power. One such system is planned to use a load of mass 2500 tonnes. The load will be at the top of a shaft. The load will be lowered down the shaft at a steady speed. A useful power output of 15 MW will be generated. The system will have an efficiency of 80%. Calculate the speed of the load. (1 tonne = 1000 kg)