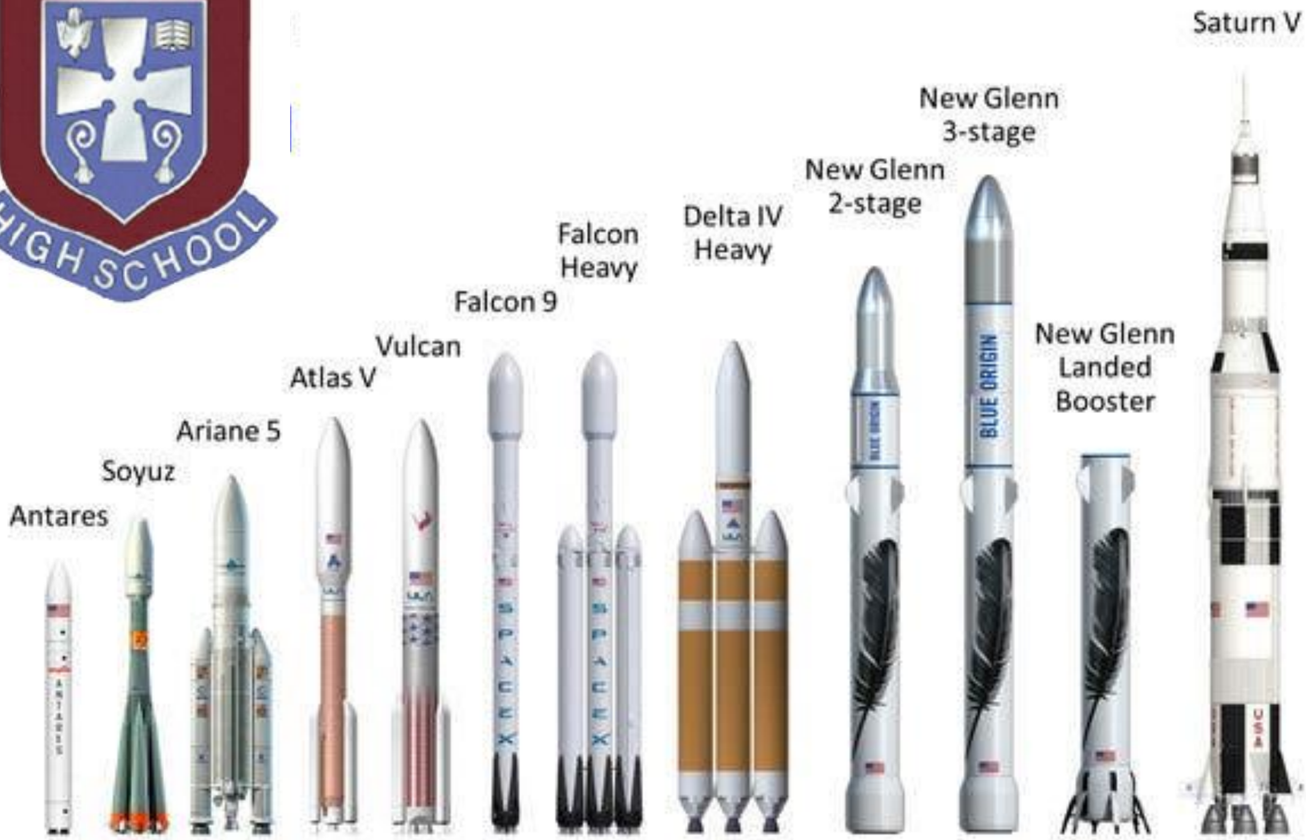
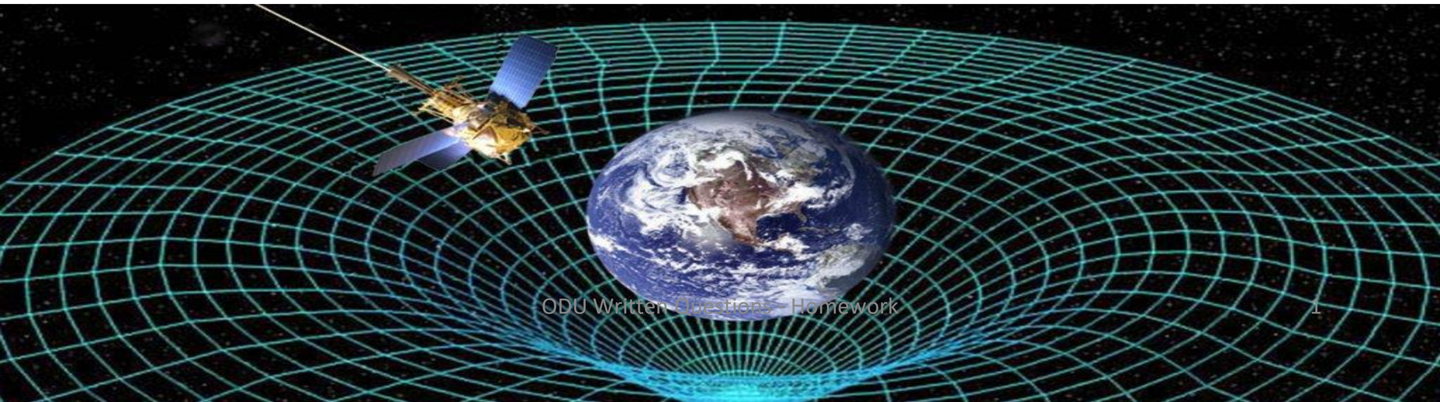
HIGHER PHYSICS



UNIT 1
Our Dynamic Universe (ODU)

WRITTEN QUESTIONS
2000 - 2019



Unit 1 Homework

Uncertainty

2002 Q21b, 2007 Q28b(I,ii), 2016 Q2(a,b)

Vectors

2004 Q21, 2007 Q21Motion

Motion

2008 Q22b(I,ii), 2011 Q21a, 2013 Q21(a,b)

Forces, Energy & Power

2001 Q21, 2005 Q22, 2006 Q21

Collisions, Explosions &Impulse

2000 Q22(a,b), 2002 Q23, 2010 Q22

Gravitation – Projectiles

2000 Q21, 2003 Q21

Gravitation – Universal Law of Gravitation

2012 Q33, 2013 Q23

Relativity

2013 Q24, 2015 Q24

Expanding Universe

2012 Q22, 2013 Q25

Uncertainties

2016	Q2	Equations of Motion
2010	Q24	Uncertainty
2000	Q24	Capacitance
2002	Q21	Impulse
2005	Q21a	Equations of Motion
2007	Q28b(i,ii)	Waves
2009	Q22	Impulse
2012	Q29	Diffraction Grating
2014	Q21	Equations of Motion

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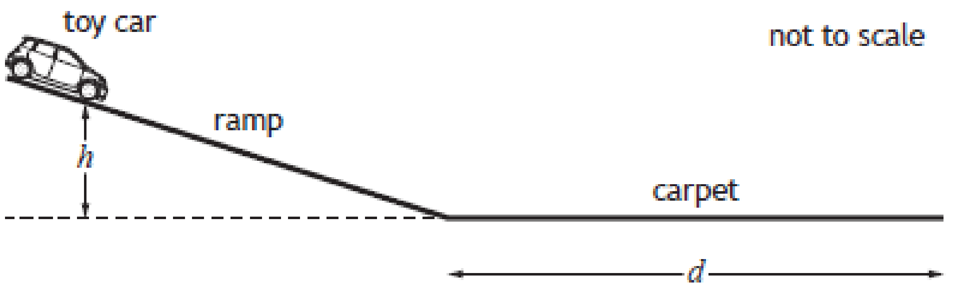
2016 Q2

2. A student uses the apparatus shown to investigate the force of friction between the wheels of a toy car and a carpet.



The toy car is released from rest, from a height h. It then travels down the ramp and along the carpet before coming to rest. The student measures the distance d that the car travels along the carpet.

The student repeats the procedure several times and records the following measurements and uncertainties.

Mass of car, m: (0·20 ± 0·01) kg

Height, h: (0·40 ± 0·005) m

Distance, d: 1·31 m   1·40 m   1·38 m   1·41 m   1·35 m

(a) (i) Calculate the mean distance d travelled by the car. **1**

(ii) Calculate the approximate random uncertainty in this value. **2**

(b) Determine which of the quantities; mass m, height h or mean distance d, has the largest percentage uncertainty.

You must justify your answer by calculation. **4**

2010 Q24

24. An experiment is carried out to measure the time taken for a steel ball to fall vertically through a fixed distance using an electronic timer.

(*a*) The experiment is repeated and the following values for time recorded.

0·49 s,   0·53 s,   0·50 s,   0·50 s,   0·55 s,   0·51 s.

Calculate:

(i) the mean value of the time; **1**

(ii) the approximate random uncertainty in the mean value of the time. **1**

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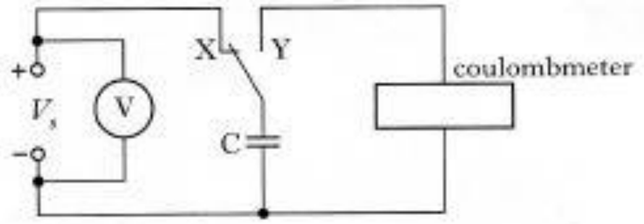
2000

24. (*a*) In an experiment to measure the capacitance of a capacitor, a student sets up the following circuit.



When the switch is in position X, the capacitor charges up to the supply voltage, V_s. When the switch is in position Y, the coulombmeter indicates the charge stored by the capacitor.

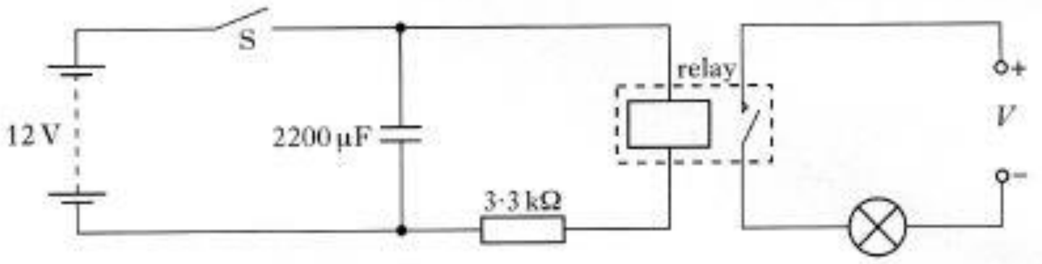
The student records the following measurements and uncertainties.

Reading on voltmeter = $(2 \cdot 56 \pm 0 \cdot 01)$ V
Reading on coulombmeter = (32 ± 1) μC

Calculate the value of the capacitance and the percentage uncertainty in this value. You must give the answer in the form

value ± percentage uncertainty. **3**

(*b*) The student designs the circuit shown below to switch off a lamp after a certain time.



The 12 V battery has negligible internal resistance.

The relay contacts are normally open. When there is a current in the relay coil the contacts close and complete the lamp circuit.

Switch S is initially closed and the lamp is on.

(i) What is the maximum energy stored in the capacitor?

(ii) (A) Switch S is now opened. Explain why the lamp stays lit for a few seconds.

(B) The 2200 μF capacitor is replaced with a 1000 μF capacitor.

Describe and explain the effect of this change on the operation of the circuit. **6**

(9)

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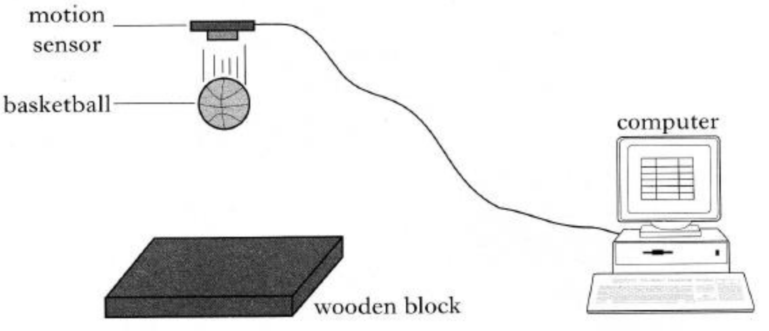
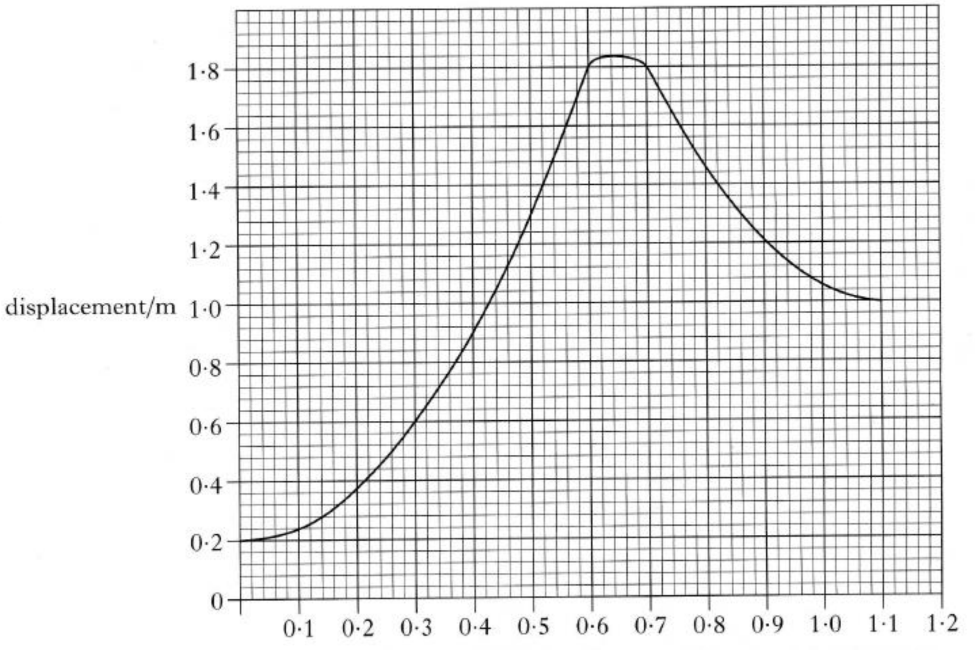
2002

21. A basketball is held below a motion sensor. The basketball is released from rest and falls onto a wooden block. The motion sensor is connected to a computer so that graphs of the motion of the basketball can be displayed.



A displacement-time graph for the motion of the basketball from the instant of its release is shown.



(*a*) (i) What is the distance between the motion sensor and the top of the basketball when it is released?

(ii) How far does the basketball fall before it hits the wooden block?

(iii) Show, by calculation, that the acceleration of the basketball as it falls is $8{\cdot}9\,m\,s^{-2}$. **3**

(*b*) The basketball is now dropped several times from the same height. The following values are obtained for the acceleration of the basketball.

$8{\cdot}9\,m\,s^{-2}$ $9{\cdot}1\,m\,s^{-2}$ $8{\cdot}4\,m\,s^{-2}$ $8{\cdot}5\,m\,s^{-2}$ $9{\cdot}0\,m\,s^{-2}$

Calculate:

(i) the mean of these values;

(ii) the approximate random uncertainty in the mean. **3**

(*c*) The wooden block is replaced by a block of sponge of the same dimensions. The experiment is repeated and a new graph obtained.

Describe and explain any **two** differences between this graph and the original graph. **2**

(8)

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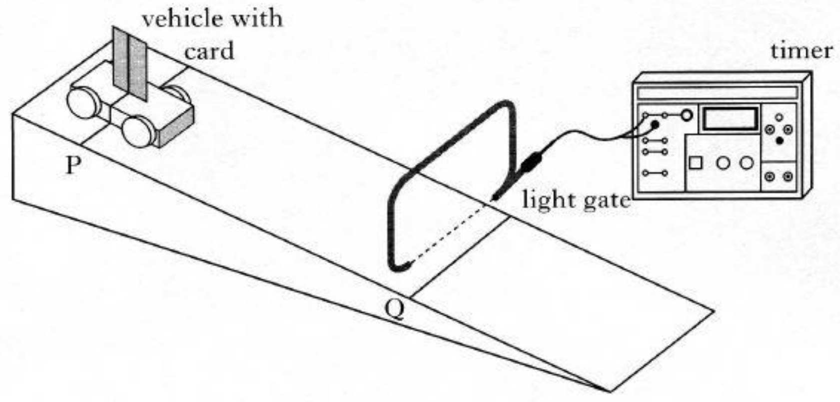
2005

21. (*a*) A student uses the apparatus shown to measure the average acceleration of a trolley travelling down a track.



The line on the trolley is aligned with line P on the track.

The trolley is released from rest and allowed to run down the track.

The timer measures the time for the card to pass through the light gate.

This procedure is repeated a number of times and the results shown below.

0·015 s 0·013 s 0·014 s 0·019 s 0·017 s 0·018 s

(i) Calculate:

(A) the mean time for the card to pass through the light gate; **1**

(B) the approximate absolute random uncertainty in this value. **1**

(ii) The length of the card is 0·020 m and the distance PQ is 0·60 m.

Calculate the acceleration of the trolley (an uncertainty in this value is not required). **3**

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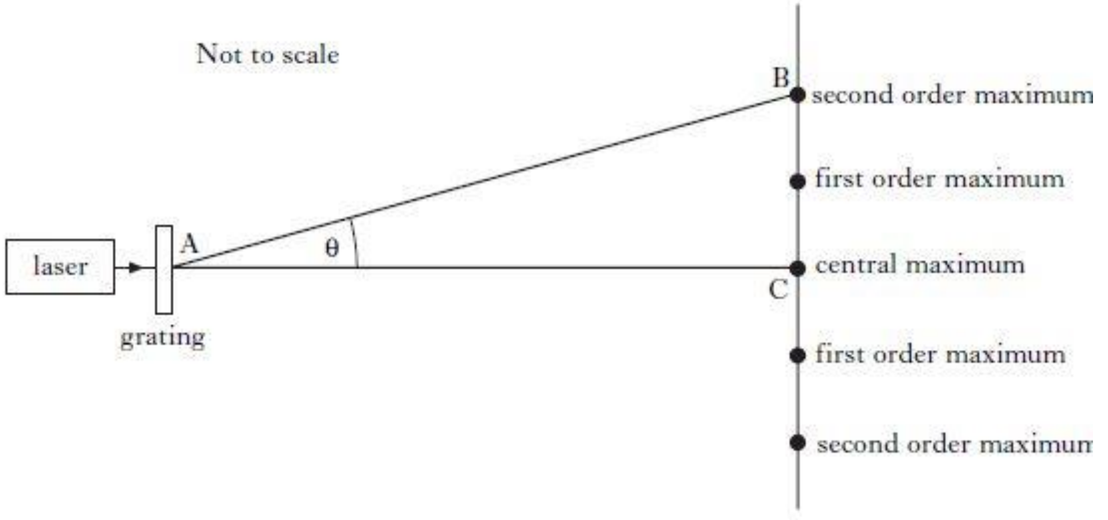
2007

Marks

28. An experiment to determine the wavelength of light from a laser is shown.



A **second** order maximum is observed at point B.

(*a*) Explain in terms of waves how a maximum is formed. **1**

(*b*) Distance AB is measured six times.

The results are shown.

1·11 m   1·08 m   1·10 m   1·13 m   1·11 m   1·07 m

(i) Calculate:

(A) the mean value for distance AB; **1**

(B) the approximate random uncertainty in this value. **1**

(ii) Distance BC is measured as (270 ± 10) mm.

Show whether AB or BC has the larger percentage uncertainty. **2**

(iii) The spacing between the lines on the grating is $4{\cdot}00 \times 10^{-6}$ m.

Calculate the wavelength of the light from the laser.

Express your answer in the form

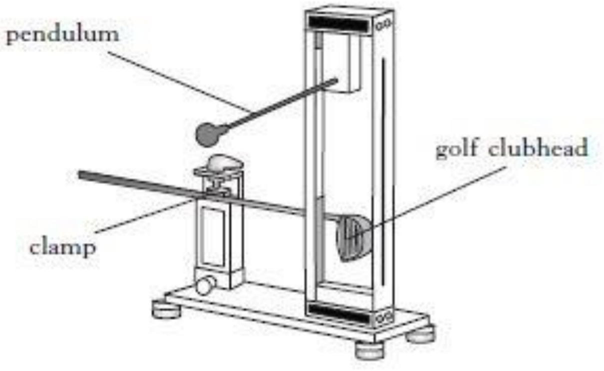
wavelength ± **absolute** uncertainty **3**

(8)

2009

22. Golf clubs are tested to ensure they meet certain standards.

(a) In one test, a securely held clubhead is hit by a small steel pendulum. The time of contact between the clubhead and the pendulum is recorded.



The experiment is repeated several times.

The results are shown.

248 μs   259 μs   251 μs   263 μs   254 μs

(i) Calculate:

(A) the mean contact time between the clubhead and the pendulum; **1**

(B) the approximate absolute random uncertainty in this value. **1**

(ii) In this test, the standard required is that the maximum value of the mean contact time must not be greater than 257 μs.

Does the club meet this standard?

You must justify your answer. **1**

(b) In another test, a machine uses a club to hit a stationary golf ball.

The mass of the ball is $4 \cdot 5 \times 10^{-2}$ kg. The ball leaves the club with a speed of $50 \cdot 0\ \mathrm{m\,s^{-1}}$. The time of contact between the club and ball is 450 μs.

(i) Calculate the average force exerted on the ball by the club. **2**

(ii) The test is repeated using a different club and an identical ball. The machine applies the same average force on the ball but with a longer contact time.

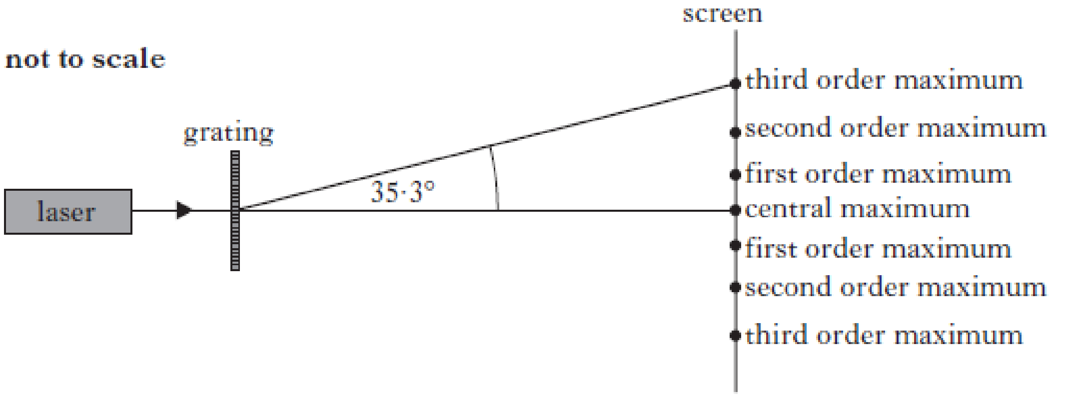
What effect, if any, does this have on the speed of the ball as it leaves the club?

Justify your answer. **2**

(7)

2012

29. A manufacturer claims that a grating consists of $3{\cdot}00 \times 10^5$ lines per metre and is accurate to $\pm 2{\cdot}0\%$. A technician decides to test this claim. She directs laser light of wavelength 633 nm onto the grating.



She measures the angle between the central maximum and the third order maximum to be 35·3°.

(*a*) Calculate the value she obtains for the slit separation for this grating. **2**

(*b*) What value does she determine for the number of lines per metre for this grating? **1**

(*c*) Does the technician's value for the number of lines per metre agree with the manufacturer's claim of $3{\cdot}00 \times 10^5$ lines per metre $\pm 2{\cdot}0\%$?

You must justify your answer by calculation. **2**

(5)

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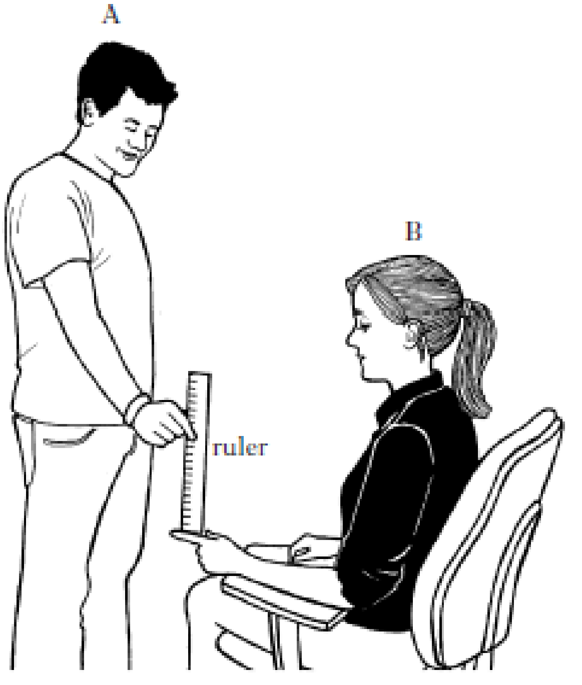
2014

21. Two students are investigating reaction time. Student A holds a ruler vertically between the fingers of student B as shown.



Student A then releases the ruler from rest and student B catches it as quickly as she can. The distance that the ruler falls before being caught is measured. The experiment is repeated a number of times and the following distances recorded.

0·164 m 0·190 m 0·188 m 0·155 m 0·163 m

(*a*) Calculate:

(i) the mean value of the distance fallen; **1**

(ii) the approximate random uncertainty in this value. **1**

(*b*) Use the mean value of the distance fallen to calculate the reaction time of student B. The uncertainty in the reaction time is not required. **2**

(4)

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Vectors and…

2004	Q21	Equations of Motion
2005	Q22a (i)	Forces
2007	Q21	Equations of Motion
2010	Q21a	Motion and Forces
2010	Q23b	Forces
2012	Q21	Equations of Motions
2014	Q21a	Forces

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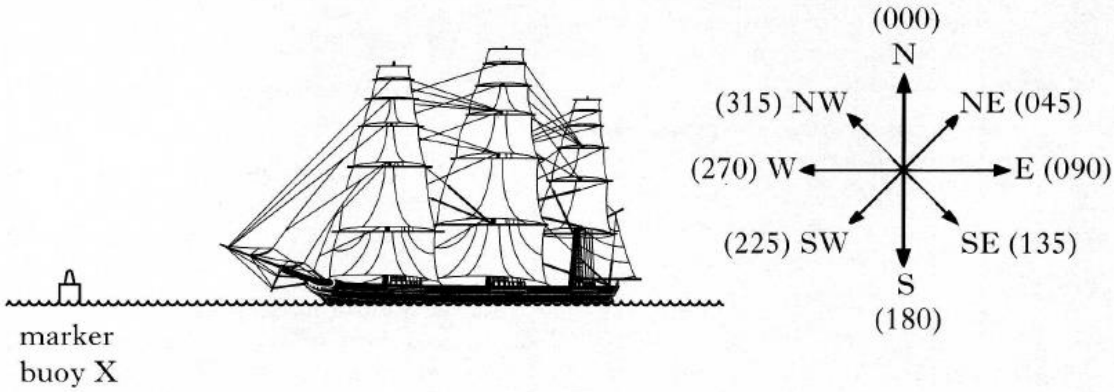
2004

21. (*a*) State the difference between speed and velocity. **1**

(*b*) During a tall ships race, a ship called the Mir passes a marker buoy X and sails due West (270). It sails on this course for 30 minutes at a speed of $10{\cdot}0\,\mathrm{km\,h^{-1}}$, then changes course to 20° West of North (340). The Mir continues on this new course for 1½ hours at a speed of $8{\cdot}0\,\mathrm{km\,h^{-1}}$ until it passes marker buoy Y.



(i) Show that the Mir travels a total distance of 17 km between marker buoys X and Y.

(ii) By scale drawing or otherwise, find the displacement from marker buoy X to marker buoy Y.

(iii) Calculate the average velocity, in $\mathrm{km\,h^{-1}}$, of the Mir between marker buoys X and Y. **6**

(*c*) A second ship, the Leeuvin, passes marker buoy X 15 minutes after the Mir and sails directly for marker buoy Y at a speed of $7{\cdot}5\,\mathrm{km\,h^{-1}}$.

Show by calculation which ship first passes marker buoy Y. **2**

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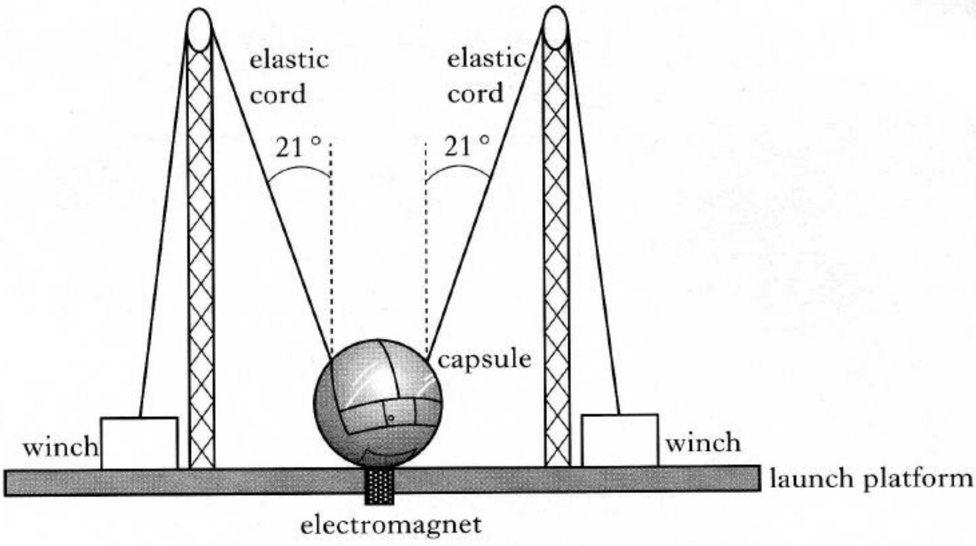
2005

22. A "giant catapult" is part of a fairground ride.



Two people are strapped into a capsule. The capsule and the occupants have a combined mass of 236 kg.

The capsule is held stationary by an electromagnet while the tension in the elastic cords is increased using the winches.

The mass of the elastic cords and the effects of air resistance can be ignored.

(*a*) When the tension in each cord reaches $4 \cdot 5 \times 10^3$ N the electromagnet is switched off and the capsule and occupants are propelled vertically upwards.

(i) Calculate the vertical component of the force exerted by **each** cord just before the capsule is released. **1**

(ii) Calculate the initial acceleration of the capsule. **3**

(iii) Explain why the acceleration of the capsule decreases as it rises. **1**

(*b*) Throughout the ride the occupants remain upright in the capsule.

A short time after release the occupants feel no force between themselves and the seats.

Explain why this happens. **1**

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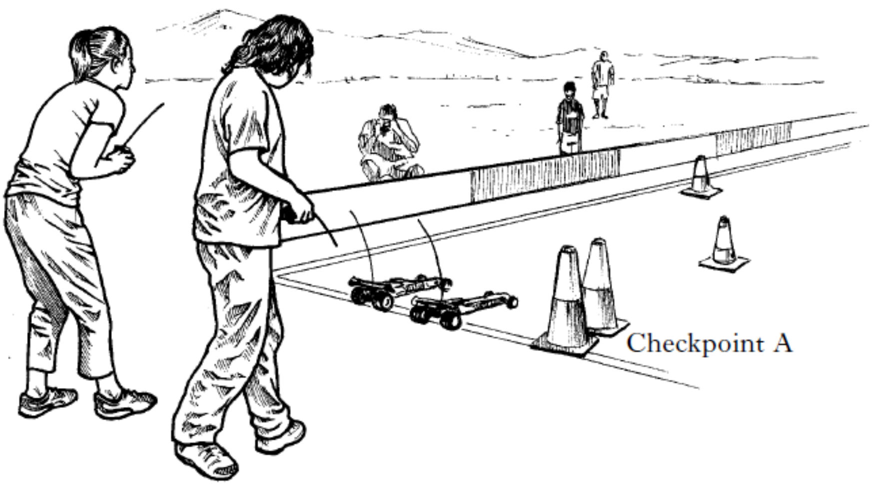
2007

21. Competitors are racing remote control cars. The cars have to be driven over a precise route between checkpoints.



Each car is to travel from checkpoint A to checkpoint B by following these instructions.

"Drive 150 m due North, then drive 250 m on a bearing of 60° East of North (060)."

Car X takes 1 minute 6 seconds to follow these instructions exactly.

(*a*) By scale drawing or otherwise, find the displacement of checkpoint B from checkpoint A. **2**

(*b*) Calculate the average velocity of car X from checkpoint A to checkpoint B. **2**

(*c*) Car Y leaves A at the same time as car X.

Car Y follows exactly the same route at an average speed of $6 \cdot 5\ m\ s^{-1}$.

Which car arrives first at checkpoint B?

Justify your answer with a calculation. **2**

(*d*) State the displacement of checkpoint A from checkpoint B. **1**

2010

21. A helicopter is flying at a constant height above the ground. The helicopter is carrying a crate suspended from a cable as shown.

(*a*) The helicopter flies 20 km on a bearing of 180 (due South). It then turns on to a bearing of 140 (50° South of East) and travels a further 30 km.

The helicopter takes 15 minutes to travel the 50 km.

(i) By scale drawing (or otherwise) find the resultant displacement of the helicopter. **2**

(ii) Calculate the average velocity of the helicopter during the 15 minutes. **2**

(*b*) The helicopter reaches its destination and hovers above a drop zone.

(i) The total mass of the helicopter and crate is $1{\cdot}21 \times 10^4$ kg.

Show that the helicopter produces a lift force of 119 kN. **1**

(ii) The helicopter now drops the crate which has a mass of $2{\cdot}30 \times 10^3$ kg. The lift force remains constant.

Describe the vertical motion of the helicopter immediately after the crate is dropped.

Justify your answer in terms of the forces acting on the helicopter. **2**

23. (continued)

(*b*) Another gymnast is practising on a piece of equipment called the rings. The gymnast grips two wooden rings suspended above the gym floor by strong, vertical ropes as shown in Figure 1.

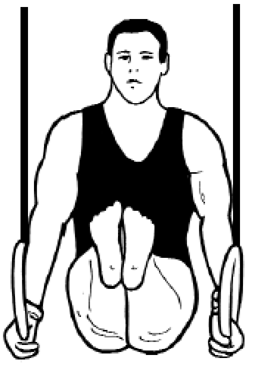


Figure 1

He now stretches out his arms until each rope makes an angle of 10° with the vertical as shown in Figure 2.

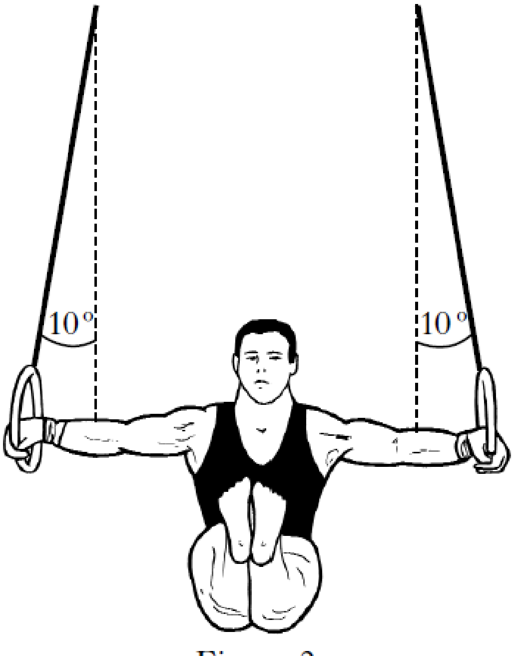


Figure 2

Explain why the tension in each rope increases as the gymnast stretches out his arms. **2**

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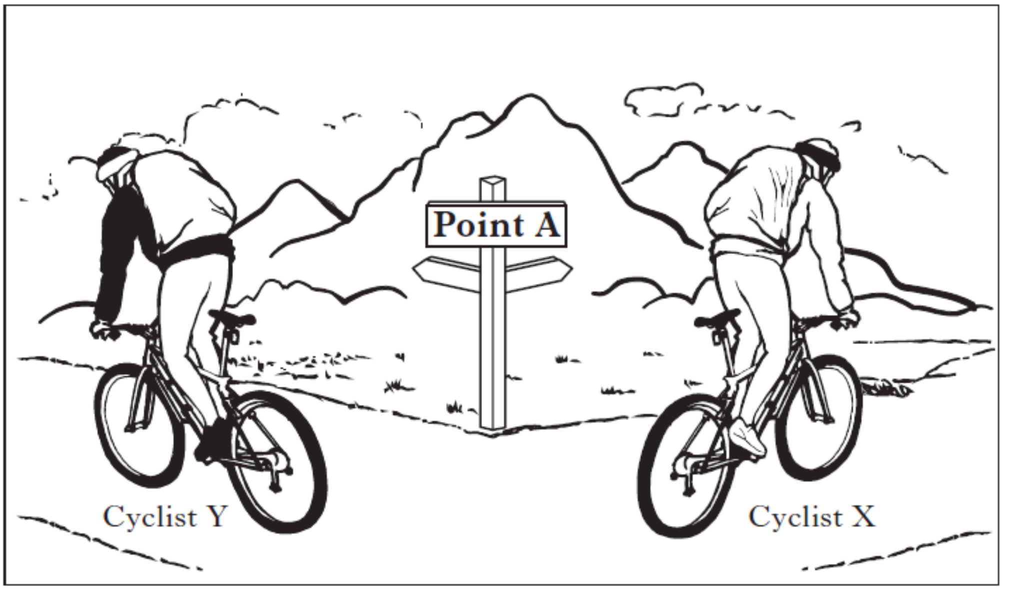
2012

21. Two cyclists choose different routes to travel from point **A** to a point **B** some distance away.



(*a*) Cyclist X travels 12 km due East (bearing 090). He then turns onto a bearing of 200 (20° West of South) and travels a further 15 km to arrive at **B**. He takes 1 hour 15 minutes to travel from **A** to **B**.

(i) By scale drawing (or otherwise) find the displacement of **B** from **A**. **2**

(ii) Calculate the average velocity of cyclist X for the journey from **A** to **B**. **2**

(*b*) Cyclist Y travels a total distance of 33 km by following a different route from **A** to **B** at an average speed of 22 km h^{-1}.

(i) State the displacement of cyclist Y on completing this route. **1**

(ii) Calculate the average velocity of cyclist Y for the journey from **A** to **B**. **3**

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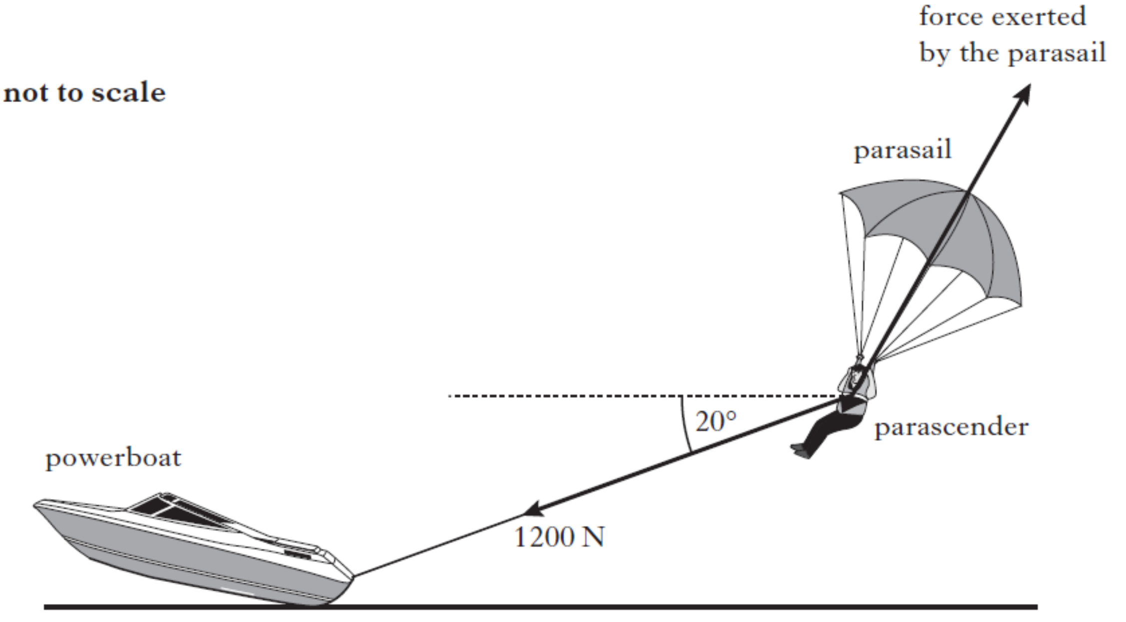
2014

22. A powerboat is used to pull a parascender at a constant speed and height.



The weight of the parascender is 900 N.

A rope exerts a force of 1200 N on the parascender at an angle of 20° to the horizontal.

Another force is exerted on the parascender by the parasail.

(*a*) The resultant force acting on the parascender is 0 N.

(i) State what is meant by the *resultant of a number of forces*. **1**

(ii) By scale drawing or otherwise, determine the magnitude and direction of the force exerted on the parascender by the parasail. **3**

(*b*) The parascender releases the rope and initially rises higher.

Explain, in terms of the forces acting, why the parascender rises. **2**

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Motion

2002	Q21a	Equations of Motion
2005	Q21a(i)	Equations of Motion
2004	Q22a (i)	Forces
2007	Q22a	Motion and Forces
2008	Q21	Forces
2008	Q22	Equations of Motions
2011	Q21	Equations of Motion
2010	Q23	Impulse
2013	Q21	Equations of Motion
2017	Q1	Equations of Motion
2010	Q23	Equations of Motion
2019	Q1	Equations of Motion

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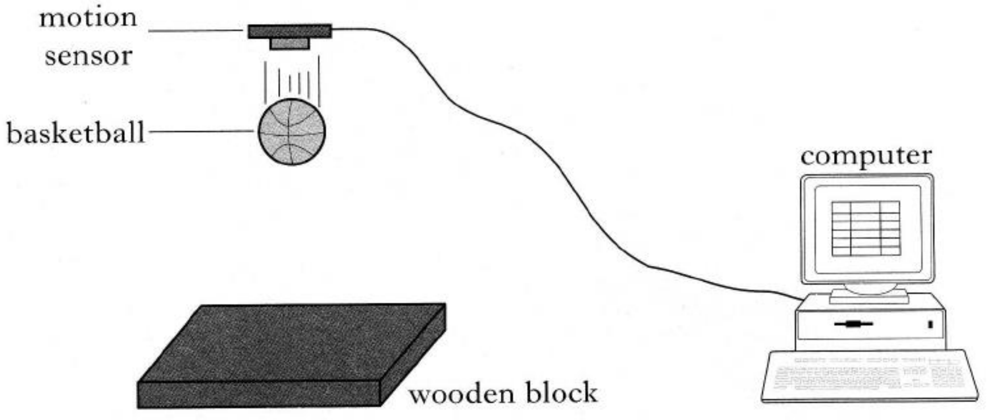
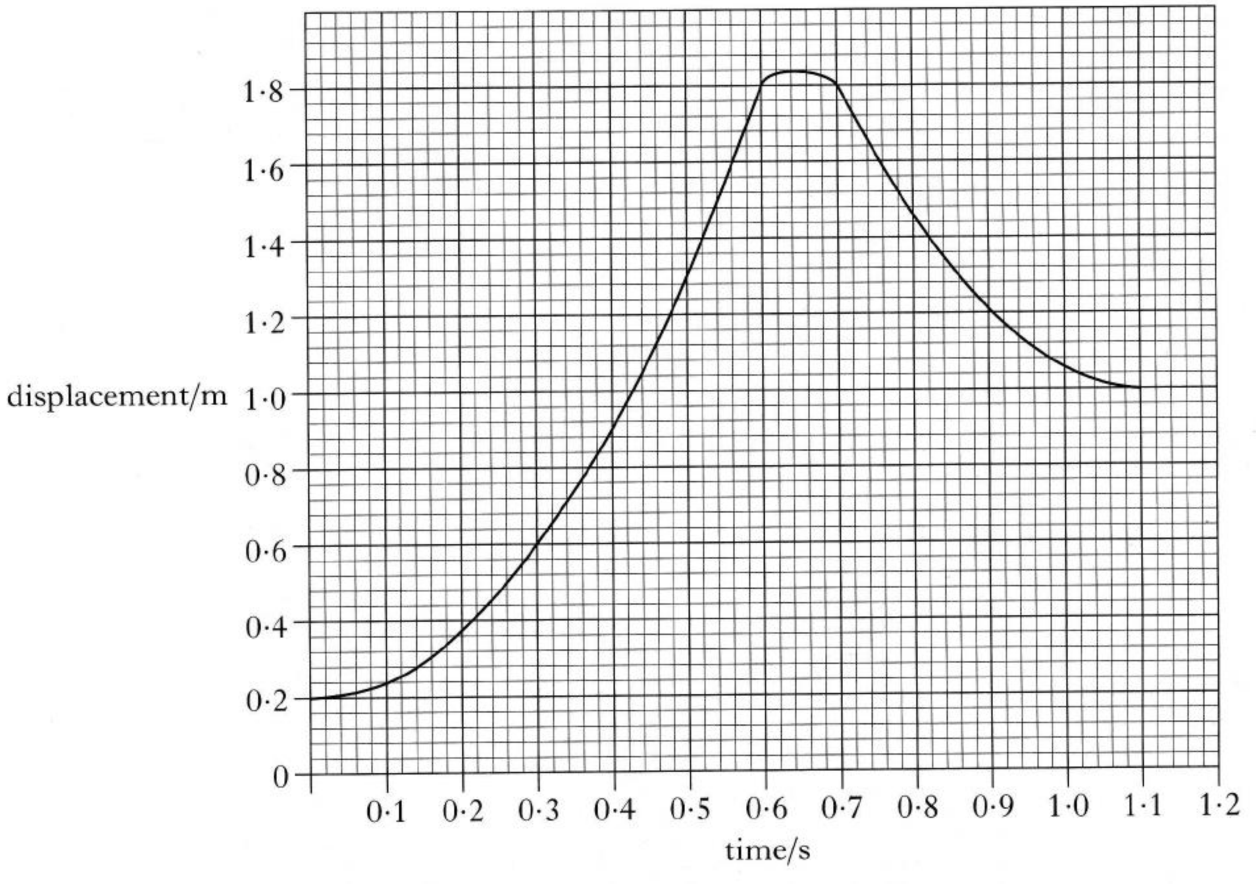
2002

21. A basketball is held below a motion sensor. The basketball is released from rest and falls onto a wooden block. The motion sensor is connected to a computer so that graphs of the motion of the basketball can be displayed.



A displacement-time graph for the motion of the basketball from the instant of its release is shown.



Continued…/

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2002

Marks

21. (continued)

(*a*) (i) What is the distance between the motion sensor and the top of the basketball when it is released?

(ii) How far does the basketball fall before it hits the wooden block?

(iii) Show, by calculation, that the acceleration of the basketball as it falls is $8{\cdot}9\,\text{m s}^{-2}$. **3**

(*b*) The basketball is now dropped several times from the same height. The following values are obtained for the acceleration of the basketball.

$8{\cdot}9\,\text{m s}^{-2}$ $9{\cdot}1\,\text{m s}^{-2}$ $8{\cdot}4\,\text{m s}^{-2}$ $8{\cdot}5\,\text{m s}^{-2}$ $9{\cdot}0\,\text{m s}^{-2}$

Calculate:

(i) the mean of these values;

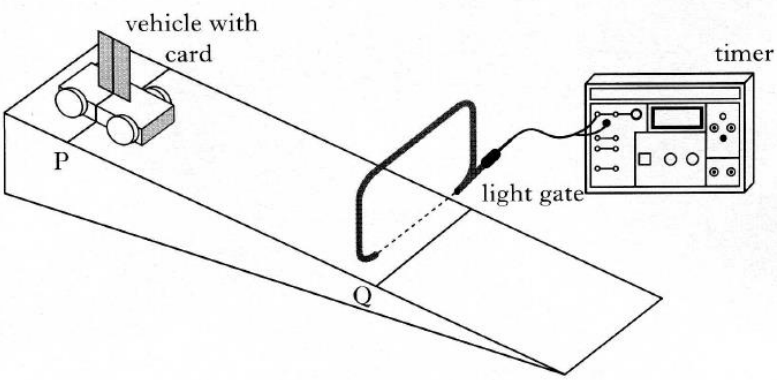
(ii) the approximate random uncertainty in the mean. **3**

(*c*) The wooden block is replaced by a block of sponge of the same dimensions. The experiment is repeated and a new graph obtained.

Describe and explain any **two** differences between this graph and the original graph. **2**

2005

21. (*a*) A student uses the apparatus shown to measure the average acceleration of a trolley travelling down a track.



The line on the trolley is aligned with line P on the track.

The trolley is released from rest and allowed to run down the track.

The timer measures the time for the card to pass through the light gate.

This procedure is repeated a number of times and the results shown below.

0·015 s 0·013 s 0·014 s 0·019 s 0·017 s 0·018 s

(i) Calculate:

(A) the mean time for the card to pass through the light gate; **1**

(B) the approximate absolute random uncertainty in this value. **1**

(ii) The length of the card is 0·020 m and the distance PQ is 0·60 m.

Calculate the acceleration of the trolley (an uncertainty in this value is not required). **3**

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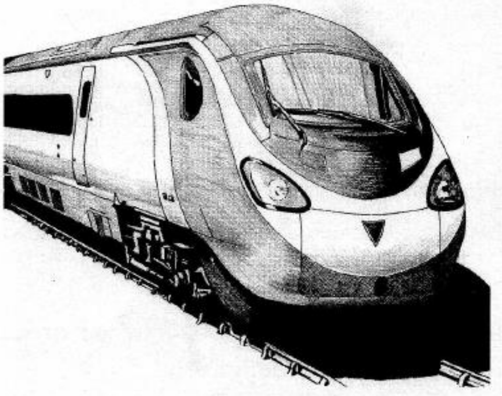
2004

Marks

22. A train of mass $7{\cdot}5 \times 10^5$ kg is travelling at $60\,m\,s^{-1}$ along a straight horizontal track.

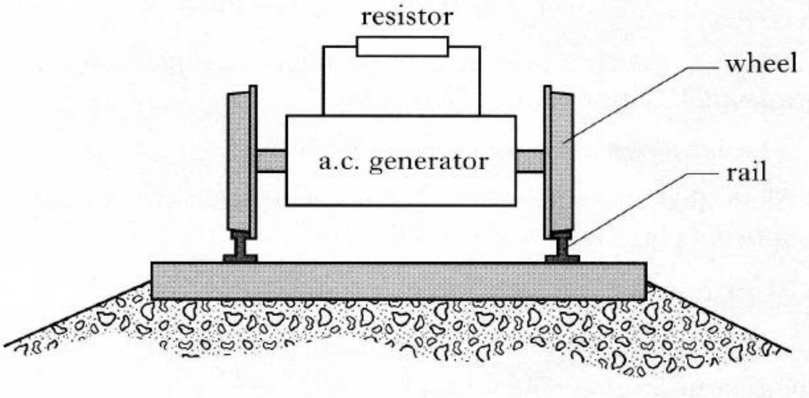


The brakes are applied and the train decelerates uniformly to rest in a time of 40 s.

(*a*) (i) Calculate the distance the train travels between the brakes being applied and the train coming to rest.

(ii) Calculate the force required to bring the train to rest in this time. **4**

(*b*) Part of the train's braking system consists of an electrical circuit as shown in the diagram.



While the train is braking, the wheels drive an a.c. generator which changes kinetic energy into electrical energy. This electrical energy is changed into heat in a resistor. The r.m.s. current in the resistor is $2{\cdot}5 \times 10^3$ A and the resistor produces $8{\cdot}5$ MJ of heat each second.

Calculate the peak voltage across the resistor. **3**

(7)

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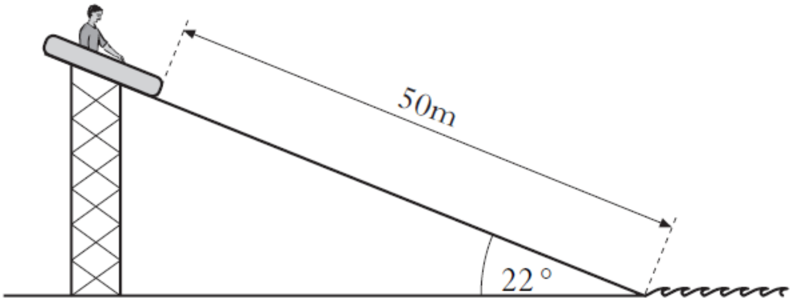
2007

22. A fairground ride consists of rafts which slide down a slope into water.



The slope is at an angle of 22° to the horizontal. Each raft has a mass of 8·0 kg. The length of the slope is 50 m.

A child of mass 52 kg sits in a raft at the top of the slope. The raft is released from rest. The child and raft slide together down the slope into the water. The force of friction between the raft and slope remains constant at 180 N.

(*a*) Calculate the component of weight, in newtons, of the child and raft down the slope. **1**

(*b*) Show by calculation that the acceleration of the child and raft down the slope is 0·67 $m\,s^{-2}$. **2**

(*c*) Calculate the speed of the child and raft at the bottom of the slope. **2**

(*d*) A second child of smaller mass is released from rest in an identical raft at the same starting point. The force of friction is the same as before.

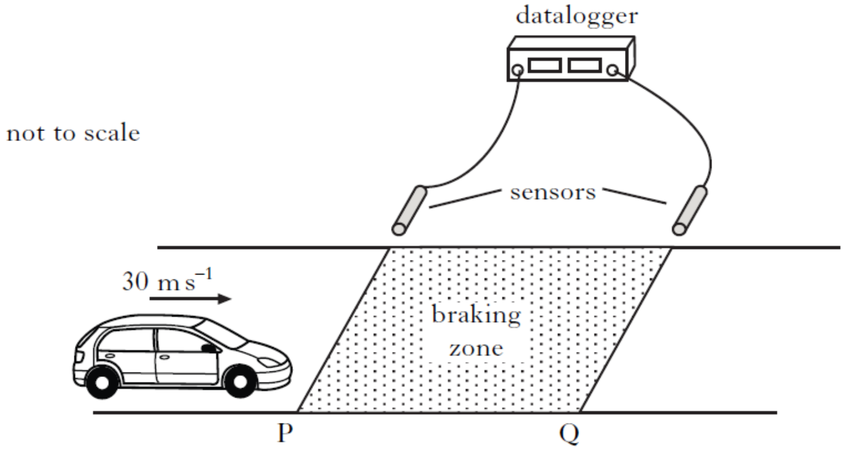
How does the speed of this child and raft at the bottom of the slope compare with the answer to part (*c*)?

Justify your answer. **2**

(7)

2008

21. To test the braking system of cars, a test track is set up as shown.



The sensors are connected to a datalogger which records the speed of a car at both P and Q.

A car is driven at a constant speed of 30 m s^{-1} until it reaches the start of the braking zone at P. The brakes are then applied.

(*a*) In one test, the datalogger records the speed at P as 30 m s^{-1} and the speed at Q as 12 m s^{-1}. The car slows down at a constant rate of 9·0 m s^{-2} between P and Q.

Calculate the length of the braking zone. **2**

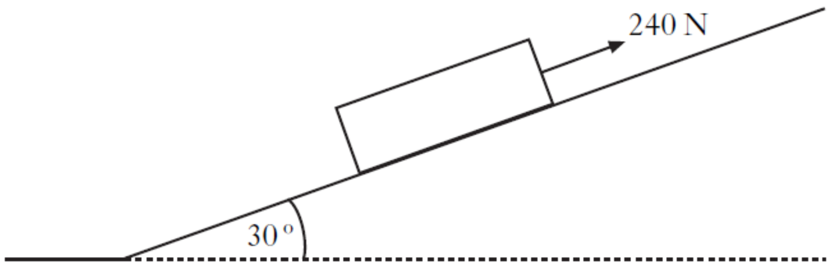
(*b*) The test is repeated. The same car is used but now with passengers in the car. The speed at P is again recorded as 30 m s^{-1}.

The same braking force is applied to the car as in part (*a*).

How does the speed of the car at Q compare with its speed at Q in part (*a*)? Justify your answer. **2**

22. A crate of mass 40·0 kg is pulled up a slope using a rope.

The slope is at an angle of 30° to the horizontal.



A force of 240 N is applied to the crate parallel to the slope.

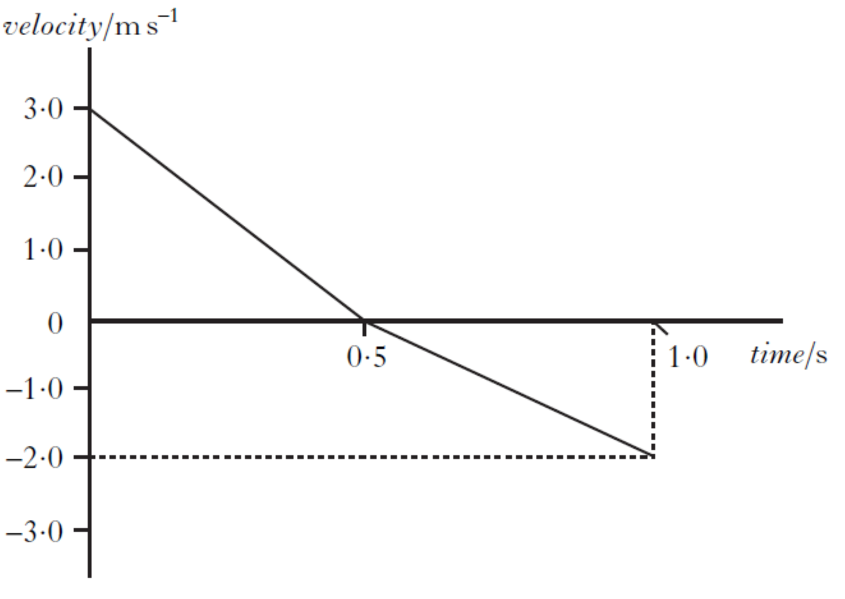
The crate moves at a constant speed of $3{\cdot}0\ \mathrm{m\,s^{-1}}$.

(*a*) (i) Calculate the component of the weight of the crate acting parallel to the slope. **2**

(ii) Calculate the frictional force acting on the crate. **2**

(*b*) As the crate is moving up the slope, the rope snaps.

The graph shows how the velocity of the crate changes from the moment the rope snaps.



(i) Describe the motion of the crate during the first 0·5 s after the rope snaps. **1**

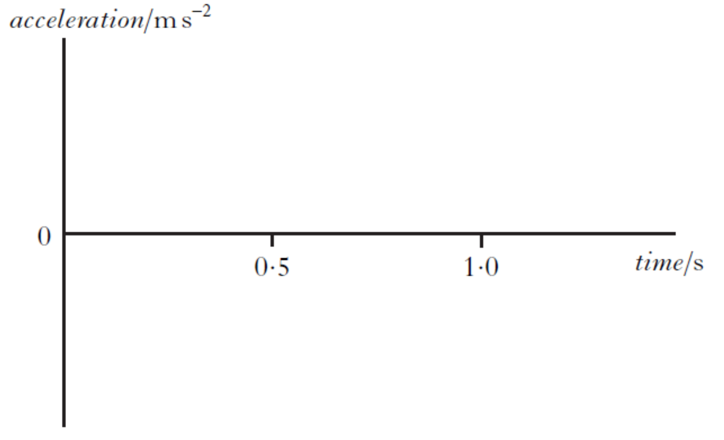
Continued…/

Return to Homework Contents

22. (*b*) (continued)

(ii) Copy the axes shown below and sketch the graph to show the acceleration of the crate between 0 and 1·0 s.

Appropriate numerical values are also required on the acceleration axis. **2**



(iii) Explain, in terms of the forces acting on the crate, why the magnitude of the acceleration changes at 0·5 s. **2**

(9)

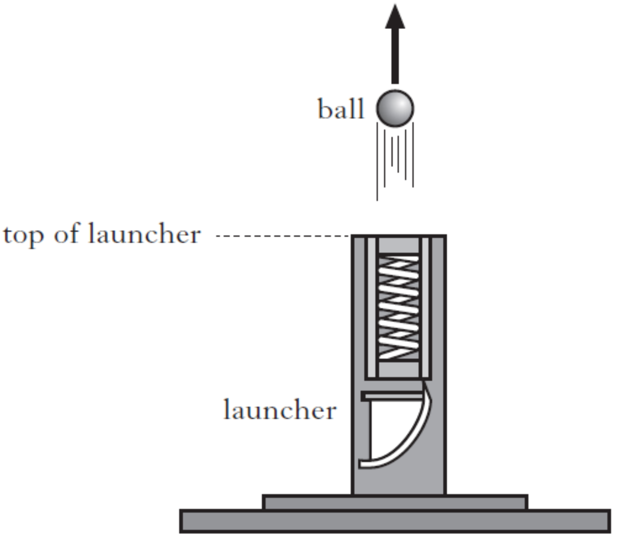
2011

21. A student investigates the motion of a ball projected from a launcher.

The launcher is placed on the ground and a ball is fired vertically upwards.

The vertical speed of the ball as it leaves the top of the launcher is 7·0 m s^{-1}.

The effects of air resistance can be ignored.



(*a*) (i) Calculate the maximum height above the top of the launcher reached by the ball. **2**

(ii) Show that the time taken for the ball to reach its maximum height is 0·71 s. **1**

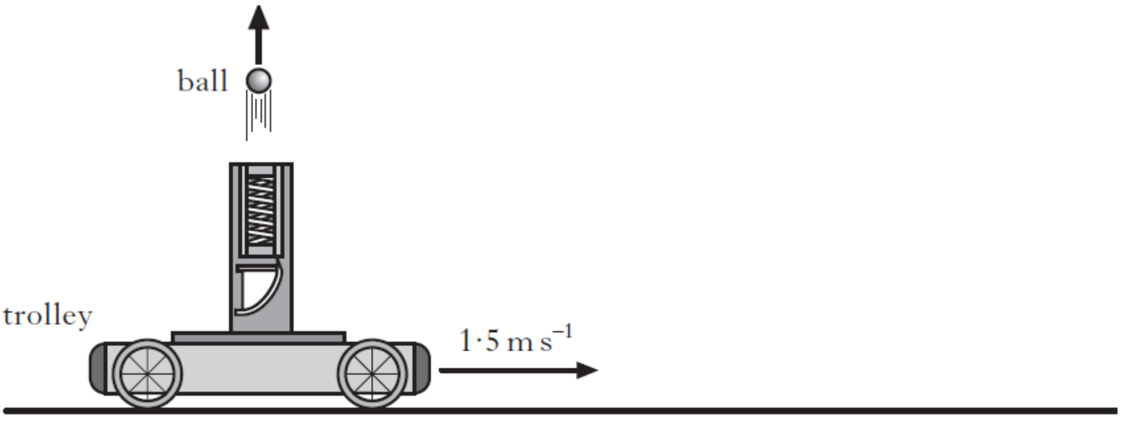
 Continued…/

Return to Homework Contents

2011

(*b*) The student now fixes the launcher to a trolley. The trolley travels horizontally at a constant speed of $1{\cdot}5\,m\,s^{-1}$ to the right.

The launcher again fires the ball vertically upwards with a speed of $7{\cdot}0\,m\,s^{-1}$.



(i) Determine the velocity of the ball after $0{\cdot}71\,s$. **1**

(ii) The student asks some friends to predict where the ball will land relative to the moving launcher. They make the following statements.

Statement X: The ball will land behind the launcher.

Statement Y: The ball will land in front of the launcher.

Statement Z: The ball will land on top of the launcher.

Which of the statements is correct?

You must justify your answer. **2**

(6)

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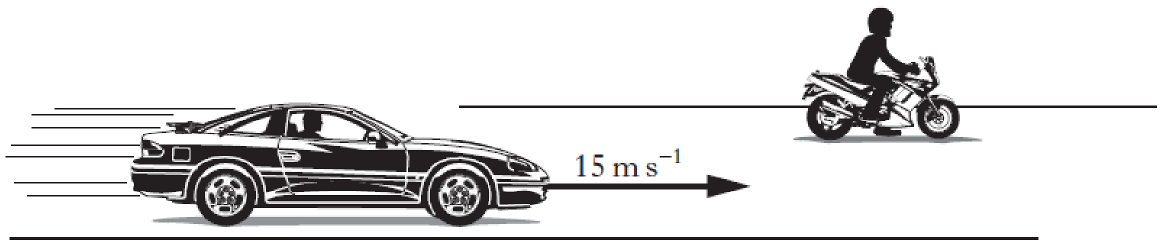
2013

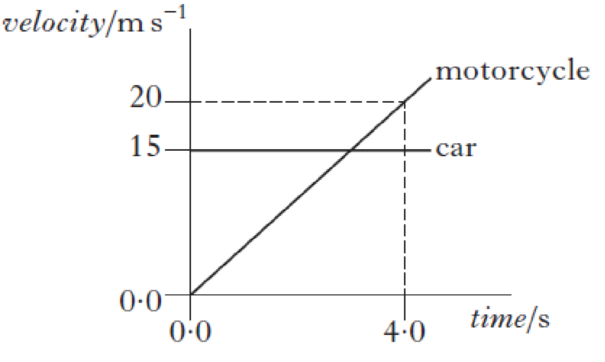
21. A car is travelling at a constant speed of $15\,m\,s^{-1}$ along a straight, level road.

It passes a motorcycle which is stationary at the roadside.



At the instant the car passes, the motorcycle starts to move in the same direction as the car.

The graph shows the motion of each vehicle from the instant the car passes the motorcycle.



(*a*) Show that the initial acceleration of the motorcycle is $5{\cdot}0\,m\,s^{-2}$. **1**

(*b*) Calculate the distance between the car and the motorcycle at 4·0 s. **2**

(*c*) The total mass of the motorcycle and rider is 290 kg. At a time of 2·0 s the driving force on the motorcycle is 1800 N.

(i) Calculate the frictional force acting on the motorcycle at this time. **2**

(ii) Explain why the driving force must be increased with time to maintain a constant acceleration. **1**

2017

1. A student is on a stationary train.

The train now accelerates along a straight level track.

The student uses an app on a phone to measure the acceleration of the train.

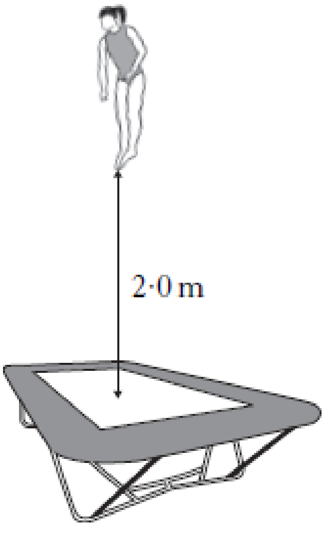
(a) The train accelerates uniformly at $0{\cdot}32\ \text{m s}^{-2}$ for 25 seconds.

(i) State what is meant by *an acceleration of $0{\cdot}32\ m\ s^{-2}$*. **1**

(ii) Calculate the distance travelled by the train in the 25 seconds. **3**

2010

23. (*a*) A gymnast of mass 40 kg is practising on a trampoline.



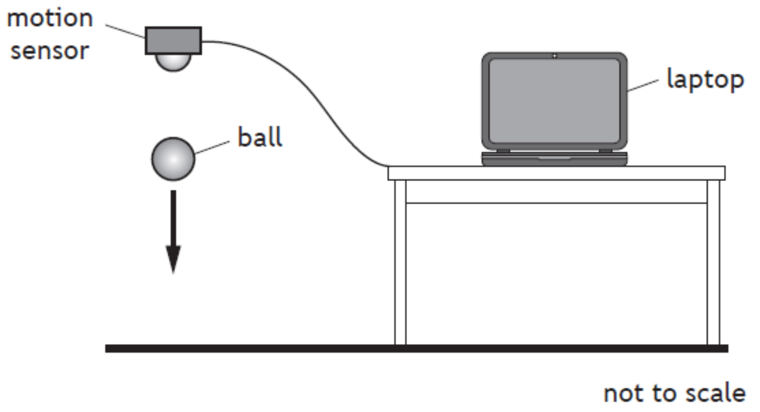
(i) At maximum height the gymnast's feet are 2·0 m above the trampoline. Show that the speed of the gymnast, as she lands on the trampoline, is $6{\cdot}3\ \text{m s}^{-1}$. **1**

(ii) The gymnast rebounds with a speed of $5{\cdot}7\ \text{m s}^{-1}$. Calculate the change in momentum of the gymnast. **2**

(iii) The gymnast was in contact with the trampoline for 0·50 s. Calculate the average force exerted by the trampoline on the gymnast. **2**

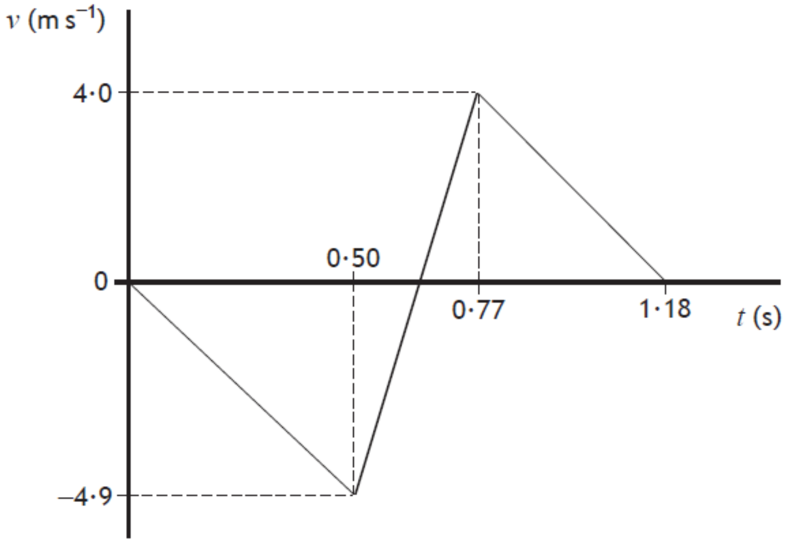
2019

1. A student carries out an experiment with a tennis ball and a motion sensor connected to a laptop.



The ball is released from rest below the sensor.

The graph shows how the vertical velocity v of the ball varies with time t, from the moment the ball is released until it rebounds to its new maximum height.



(a) Using information from the graph

(i) show that the initial acceleration of the ball is $-9{\cdot}8\ \text{m s}^{-2}$ **2**

(ii) determine the height from which the ball is released. **3**

Forces, Energy and Power

2001	Q21a	Components of Force
2004	Q22a(ii)	Forces
2005	Q22a (i)	Tension and Weight
2006	Q22a	Forces down a plane
2007	Q22	Conservation of Energy
2008	Q21	Equations of Motions
2008	Q21	Equations of Motion
2010	Q23	Newton's 2^{nd} Law
2012	Q22	Impulse
2015	Q22	Tension and Weight
2018	Q2	Newton's 2^{nd} Law

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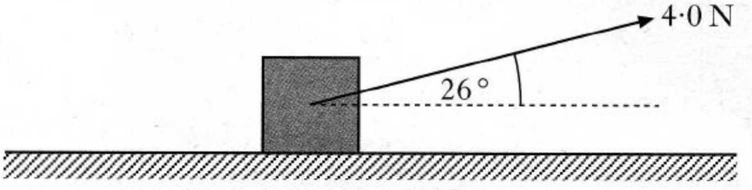
2001

21. (*a*) A box of mass 18 kg is at rest on a horizontal frictionless surface.
A force of 4·0 N is applied to the box at an angle of 26° to the horizontal.



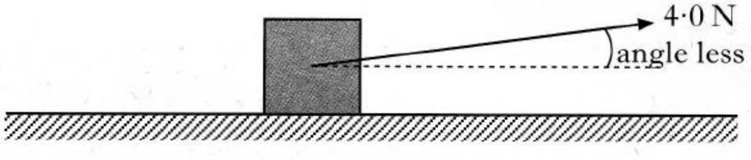
(i) Show that the horizontal component of this force is 3·6 N.

(ii) Calculate the acceleration of the box along the horizontal surface.

(iii) Calculate the horizontal distance travelled by the box in a time of 7·0 s. **5**

(*b*) The box is replaced at rest at its starting position.

The force of 4·0 N is now applied to the box at an angle of less than 26° to the horizontal.



The force is applied for a time of 7·0 s as before.

How does the distance travelled by the box compare with your answer to part (*a*)(iii)?

You must justify your answer. **2**

(7)

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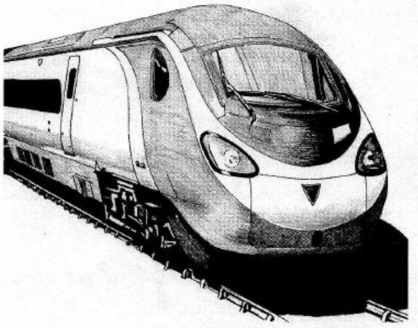
2004

22. A train of mass $7 \cdot 5 \times 10^5$ kg is travelling at $60\,m\,s^{-1}$ along a straight horizontal track.

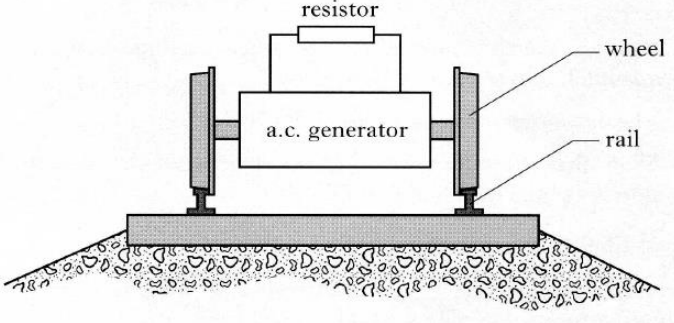


The brakes are applied and the train decelerates uniformly to rest in a time of 40 s.

(*a*) (i) Calculate the distance the train travels between the brakes being applied and the train coming to rest.

(ii) Calculate the force required to bring the train to rest in this time. **4**

(*b*) Part of the train's braking system consists of an electrical circuit as shown in the diagram.



While the train is braking, the wheels drive an a.c. generator which changes kinetic energy into electrical energy. This electrical energy is changed into heat in a resistor. The r.m.s. current in the resistor is $2 \cdot 5 \times 10^3$ A and the resistor produces 8·5 MJ of heat each second.

Calculate the peak voltage across the resistor. **3**

(7)

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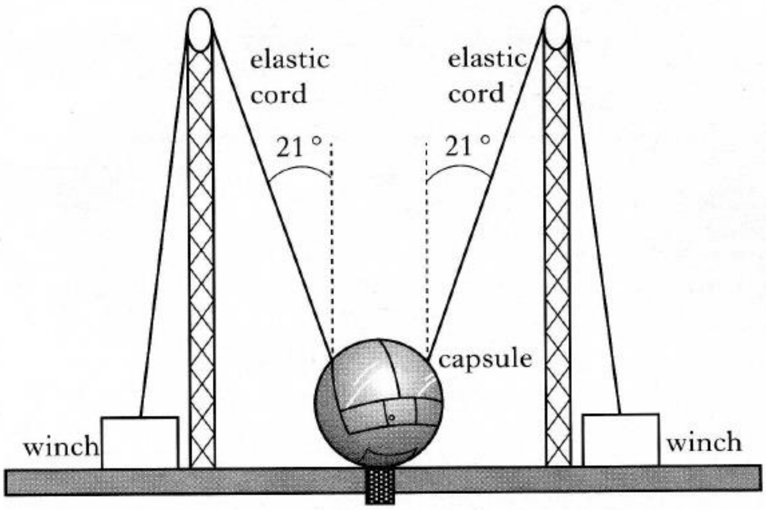
2005

22. A "giant catapult" is part of a fairground ride.



Two people are strapped into a capsule. The capsule and the occupants have a combined mass of 236 kg.

The capsule is held stationary by an electromagnet while the tension in the elastic cords is increased using the winches.

The mass of the elastic cords and the effects of air resistance can be ignored.

(*a*) When the tension in each cord reaches $4 \cdot 5 \times 10^3$ N the electromagnet is switched off and the capsule and occupants are propelled vertically upwards.

(i) Calculate the vertical component of the force exerted by **each** cord just before the capsule is released. **1**

(ii) Calculate the initial acceleration of the capsule. **3**

(iii) Explain why the acceleration of the capsule decreases as it rises. **1**

(*b*) Throughout the ride the occupants remain upright in the capsule.

A short time after release the occupants feel no force between themselves and the seats.

Explain why this happens. **1**

(6)

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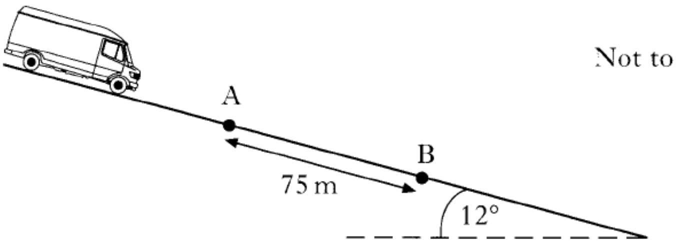
2006

21. A van of mass 2600 kg moves down a slope which is inclined at 12° to the horizontal as shown.



(*a*) Calculate the component of the van's weight parallel to the slope. **2**

(*b*) A constant frictional force of 1400 N acts on the van as it moves down the slope.

Calculate the acceleration of the van. **2**

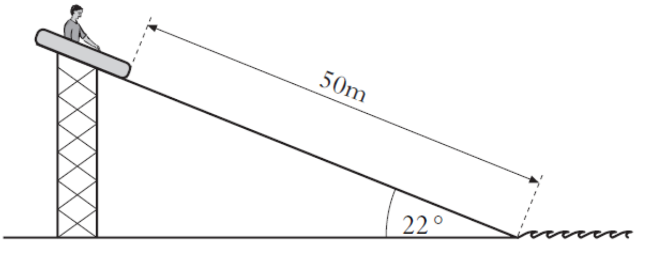
(*c*) The speed of the van as it passes point **A** is $5{\cdot}0\ \text{m s}^{-1}$.
Point **B** is 75 m further down the slope.

Calculate the kinetic energy of the van at **B**. **3**

(7)

2007

22. A fairground ride consists of rafts which slide down a slope into water.



The slope is at an angle of 22 ° to the horizontal. Each raft has a mass of 8·0 kg. The length of the slope is 50 m.

A child of mass 52 kg sits in a raft at the top of the slope. The raft is released from rest. The child and raft slide together down the slope into the water. The force of friction between the raft and slope remains constant at 180 N.

(*a*) Calculate the component of weight, in newtons, of the child and raft down the slope. **1**

(*b*) Show by calculation that the acceleration of the child and raft down the slope is $0{\cdot}67\ \text{m s}^{-2}$. **2**

(*c*) Calculate the speed of the child and raft at the bottom of the slope. **2**

(*d*) A second child of smaller mass is released from rest in an identical raft at the same starting point. The force of friction is the same as before.

How does the speed of this child and raft at the bottom of the slope compare with the answer to part (*c*)?

Justify your answer. **2**

(7)

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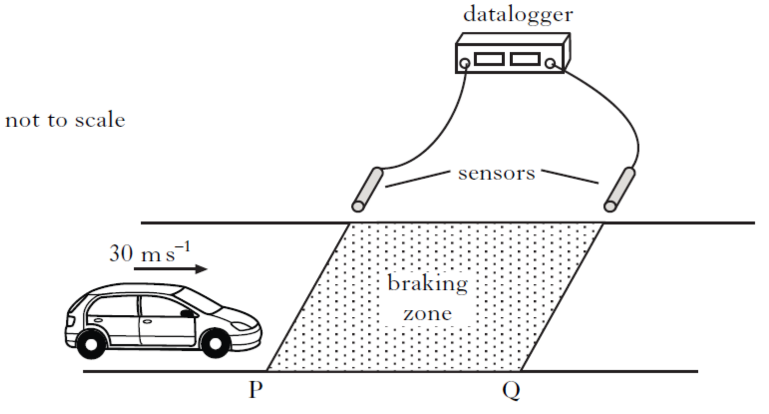
2008

21. To test the braking system of cars, a test track is set up as shown.



The sensors are connected to a datalogger which records the speed of a car at both P and Q.

A car is driven at a constant speed of $30\ m\,s^{-1}$ until it reaches the start of the braking zone at P. The brakes are then applied.

(*a*) In one test, the datalogger records the speed at P as $30\ m\,s^{-1}$ and the speed at Q as $12\ m\,s^{-1}$. The car slows down at a constant rate of $9{\cdot}0\ m\,s^{-2}$ between P and Q.

Calculate the length of the braking zone. **2**

(*b*) The test is repeated. The same car is used but now with passengers in the car. The speed at P is again recorded as $30\ m\,s^{-1}$.

The same braking force is applied to the car as in part (*a*).

How does the speed of the car at Q compare with its speed at Q in part (*a*)? Justify your answer. **2**

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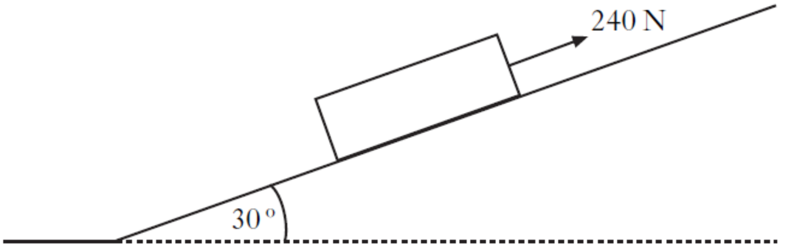
2008

22. A crate of mass 40·0 kg is pulled up a slope using a rope.

The slope is at an angle of 30° to the horizontal.



A force of 240 N is applied to the crate parallel to the slope.

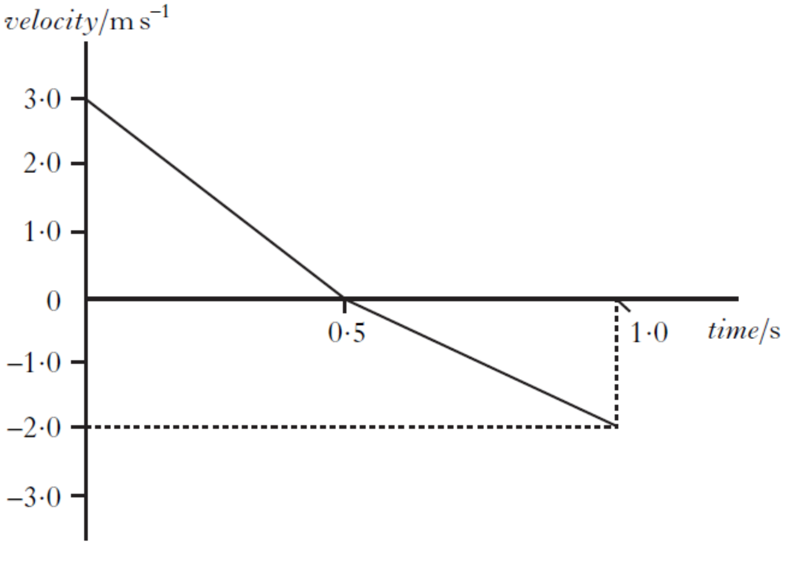
The crate moves at a constant speed of 3·0 m s^{-1}.

(*a*) (i) Calculate the component of the weight of the crate acting parallel to the slope. **2**

(ii) Calculate the frictional force acting on the crate. **2**

(*b*) As the crate is moving up the slope, the rope snaps.

The graph shows how the velocity of the crate changes from the moment the rope snaps.



(i) Describe the motion of the crate during the first 0·5 s after the rope snaps. **1**

Continued…/

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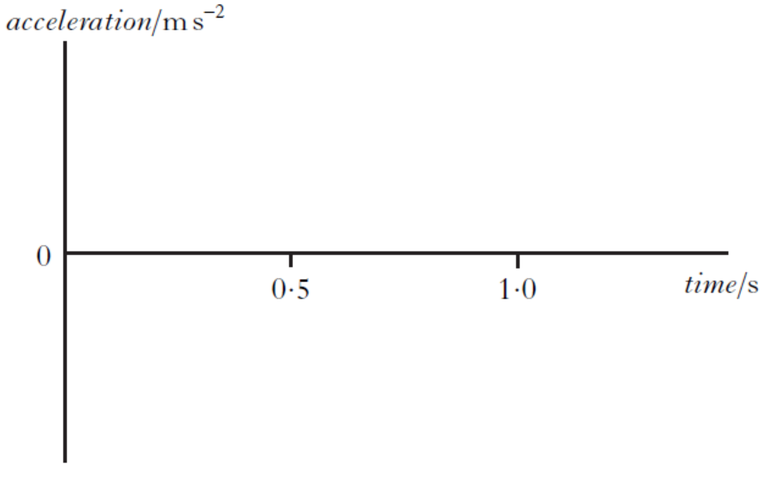
22. (b) (continued)

(ii) Copy the axes shown below and sketch the graph to show the acceleration of the crate between 0 and 1·0 s.

Appropriate numerical values are also required on the acceleration axis. **2**



(iii) Explain, in terms of the forces acting on the crate, why the magnitude of the acceleration changes at 0·5 s. **2**

(9)

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2010

21. A helicopter is flying at a constant height above the ground. The helicopter is carrying a crate suspended from a cable as shown.

(*a*) The helicopter flies 20 km on a bearing of 180 (due South). It then turns on to a bearing of 140 (50° South of East) and travels a further 30 km.

The helicopter takes 15 minutes to travel the 50 km.

(i) By scale drawing (or otherwise) find the resultant displacement of the helicopter. **2**

(ii) Calculate the average velocity of the helicopter during the 15 minutes. **2**

(*b*) The helicopter reaches its destination and hovers above a drop zone.

(i) The total mass of the helicopter and crate is $1{\cdot}21 \times 10^4$ kg.

Show that the helicopter produces a lift force of 119 kN. **1**

(ii) The helicopter now drops the crate which has a mass of $2{\cdot}30 \times 10^3$ kg. The lift force remains constant.

Describe the vertical motion of the helicopter immediately after the crate is dropped.

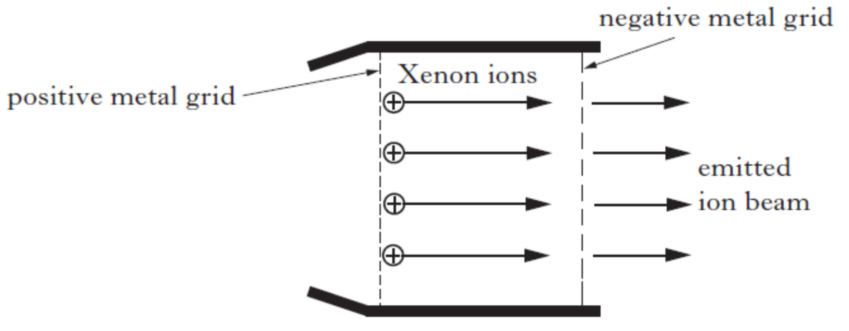
Justify your answer in terms of the forces acting on the helicopter. **2**

(7)

2012

23. An ion propulsion engine can be used to propel spacecraft to areas of deep space.

A simplified diagram of a Xenon ion engine is shown.



The Xenon ions are accelerated as they pass through an electric field between the charged metal grids. The emitted ion beam causes a force on the spacecraft in the opposite direction.

The spacecraft has a total mass of 750 kg.

The mass of a Xenon ion is $2 \cdot 18 \times 10^{-25}$ kg and its charge is $1 \cdot 60 \times 10^{-19}$ C. The potential difference between the charged metal grids is 1·22 kV.

(*a*) (i) Show that the work done on a Xenon ion as it moves through the electric field is $1 \cdot 95 \times 10^{-16}$ J. **1**

(ii) Assuming the ions are accelerated from rest, calculate the speed of a Xenon ion as it leaves the engine. **2**

(*b*) The ion beam exerts a constant force of 0·070 N on the spacecraft. Calculate the change in speed of the spacecraft during a 60 second period of time. **2**

(*c*) A different ion propulsion engine uses Krypton ions which have a smaller mass than Xenon ions. The Krypton engine emits the same number of ions per second at the same speed as the Xenon engine.

Which of the two engines produces a greater force?

Justify your answer. **2**

(7)

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2015

22. A spacecraft has a mass of 3520 kg and is descending vertically towards the surface of a moon. *Marks*

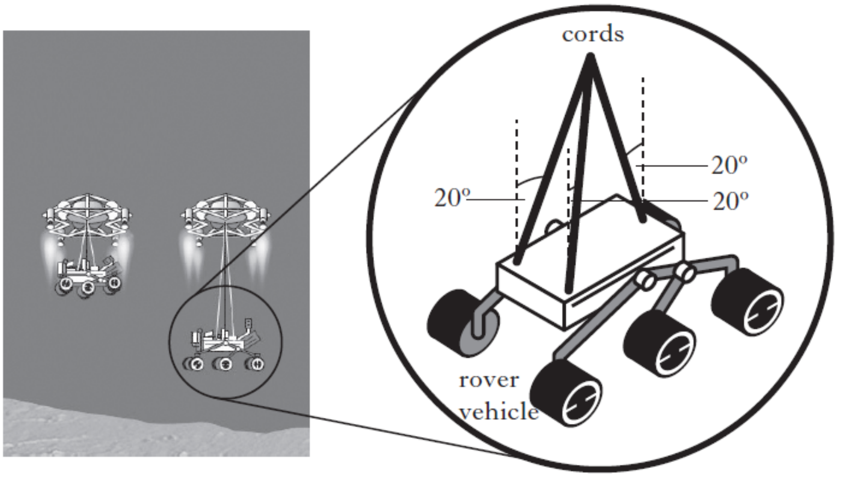
During the descent the average gravitational field strength for this moon is $1{\cdot}25\,\mathrm{N\,kg^{-1}}$.

(*a*) When the spacecraft is at a height of $2{\cdot}00 \times 10^{3}\,\mathrm{m}$ it has a vertical velocity of $90{\cdot}0\,\mathrm{m\,s^{-1}}$. Rocket engines exert a constant force on the spacecraft to reduce its speed.

This causes the speed of the spacecraft to be $0\,\mathrm{m\,s^{-1}}$ at a height of $20{\cdot}0\,\mathrm{m}$.

Calculate the average vertical force exerted by the rocket engines during this descent. **3**

(*b*) At this height of $20{\cdot}0\,\mathrm{m}$ the spacecraft is kept stationary by the rockets while a rover vehicle is lowered at a constant speed towards the surface of the moon.



The rover vehicle has a weight of 1380 N.

There are **three** cords supporting the rover as it descends.

At one instant, the angle between each cord and the vertical is 20°.

Show that the tension in each cord is 490 N at this instant. **2**

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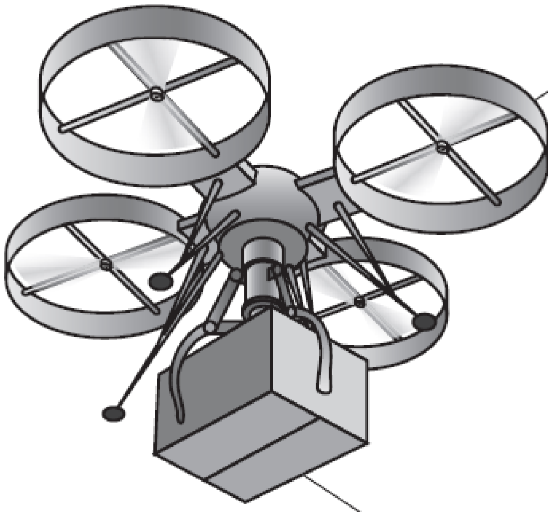
2018

2. An internet shopping company is planning to use drones to deliver packages.



(a) During a test the drone is hovering at a constant height above the ground.

The mass of the drone is 5·50 kg.

The mass of the package is 1·25 kg.

(i) Determine the upward force produced by the drone. 3

(a) (continued)

(ii) The package is now lowered using a motor and a cable.

A battery supplies 12 V across the motor. The resistance of the motor is 9·6 Ω.

Calculate the power dissipated by the motor. 3

(iii) While the package is being lowered the cable breaks.

The upward force produced by the drone remains constant.

Describe the vertical motion of the drone immediately after the cable breaks. 2

Justify your answer.

Continued…/

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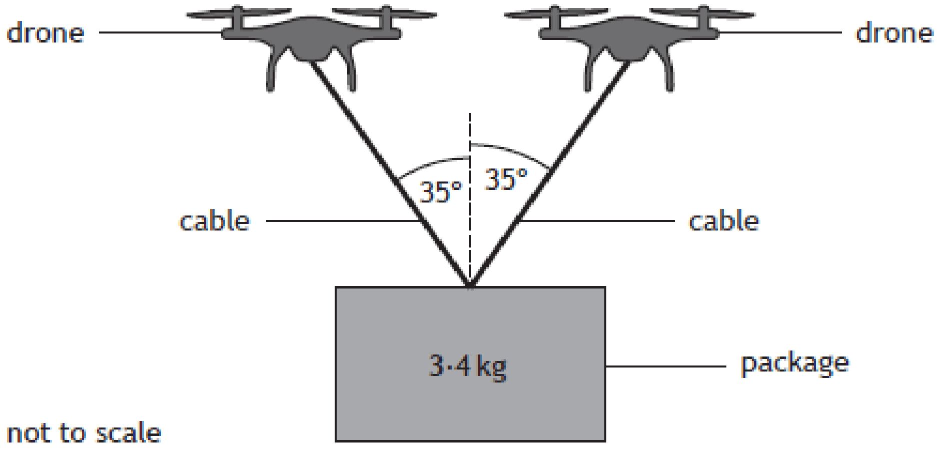
2. **(continued)**

(b) To carry a package with a greater mass two drones are used as shown.



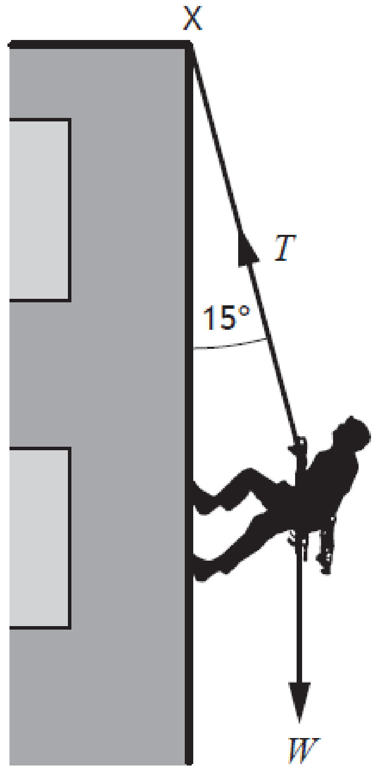
The drones are hovering at a constant height above the ground.

The mass of the package suspended from the two drones is 3·4 kg.

Determine the tension in each cable. **4**

2019

2. A student abseils down the outside of a building using a rope.



not to scale

The mass of the student is 55 kg.

The rope, of negligible mass, is attached to a fixed point X at the top of the building.

The rope makes an angle of 15° to the building.

(a) Calculate the weight W of the student. **3**

(b) Determine the tension T in the rope. **3**

(c) As the student abseils down the building the angle the rope makes with the building decreases.

State whether the tension in the rope increases, decreases or stays the same.

Justify your answer. **2**

Collisions, Explosions and Impulse

2000	Q22	
2001	Q23	
2002	Q23	
2003	Q22	
2006	Q22	
2009	Q22	
2010	Q22	
2010	Q23	
2011	Q22	
2012	Q24	
2014	Q23	
2015	Q23	
2019	Q1	(OPEN ENDED)

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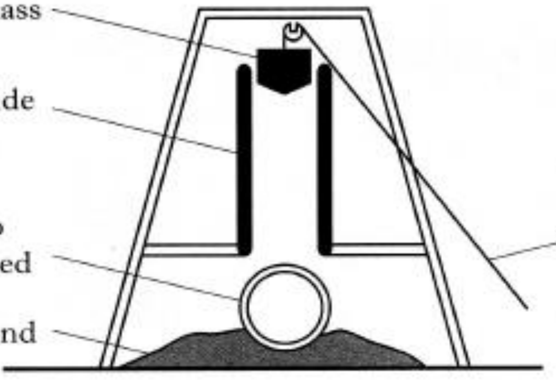
22. The apparatus shown below is used to test concrete pipes.



When the rope is released, the 15 kg mass is dropped and falls freely through a distance of 2·0 m on to the pipe.

(*a*) In one test, the mass is dropped on to an uncovered pipe.

(i) Calculate the speed of the mass just before it hits the pipe.

(ii) When the 15 kg mass hits the pipe the mass is brought to rest in a time of 0·02 s. Calculate the size and direction of the average unbalanced force on the **pipe**. **5**

(*b*) The same 15 kg mass is now dropped through the same distance on to an identical pipe which is covered with a thick layer of soft material.

Describe and explain the effect this layer has on the size of the average unbalanced force on the pipe. **2**

(*c*) Two 15 kg masses, X and Y, shaped as shown, are dropped through the same distance on to identical uncovered concrete pipes.

When the masses hit the pipes, the masses are brought to rest in the same time.

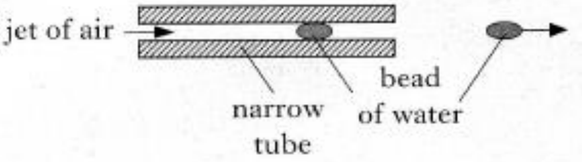
Which mass causes more damage to a pipe?

Explain your answer in terms of pressure. **2**

(9)

23. Beads of liquid moving at high speed are used to move threads in modern weaving machines.

(*a*) In one design of machine, beads of water are accelerated by jets of air as shown in the diagram.



Each bead has a mass of $2{\cdot}5 \times 10^{-5}$ kg.

When designing the machine, it was estimated that each bead of water would start from rest and experience a constant unbalanced force of 0·5 N for a time of 3·0 ms.

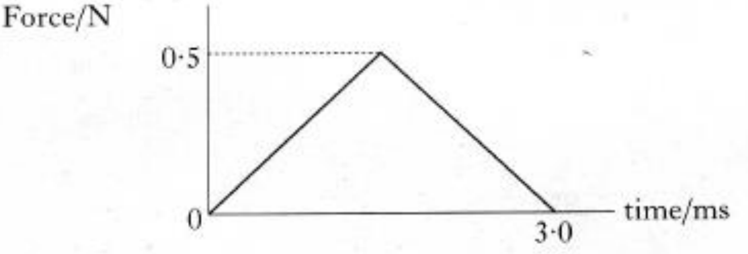
(i) Calculate:

(A) the impulse on a bead of water;

(B) the speed of the bead as it emerges from the tube.

(ii) In practice the force on a bead varies.

The following graph shows how the actual unbalanced force exerted on each bead of water varies with time.



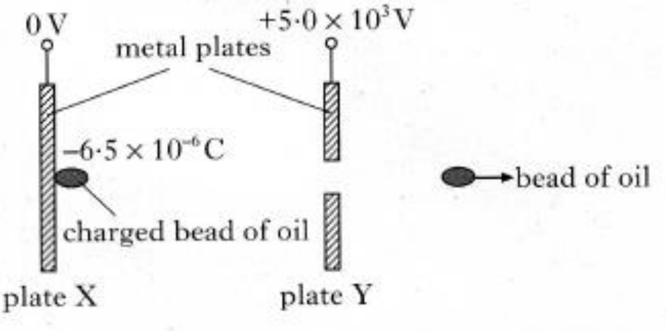
Use information from this graph to show that the bead leaves the tube with a speed equal to half of the value calculated in part (i)(B). **6**

(*b*) Another design of machine uses beads of oil and two metal plates X and Y.

The potential difference between these plates is $5{\cdot}0 \times 10^{3}$ V.

Each bead of oil has a mass of $4{\cdot}0 \times 10^{-5}$ kg and is given a negative charge of $6{\cdot}5 \times 10^{-6}$ C.

The bead accelerates from rest at plate X and passes through a hole in plate Y.



Neglecting air friction, calculate the speed of the bead at plate Y. **3**

(9)

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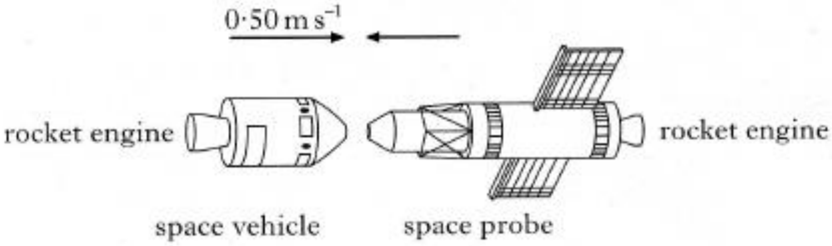
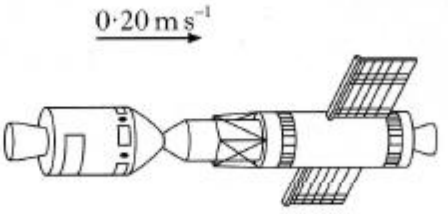
23. (*a*) A space vehicle of mass 2500 kg is moving with a constant speed of $0{\cdot}50\,\text{m s}^{-1}$ in the direction shown. It is about to dock with a space probe of mass 1500 kg which is moving with a constant speed in the opposite direction.



After docking, the space vehicle and space probe move off together at $0{\cdot}20\,\text{m s}^{-1}$ in the original direction in which the space vehicle was moving.



Calculate the speed of the space probe before it docked with the space vehicle. **2**

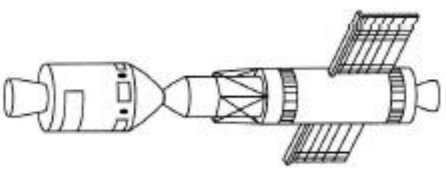
(*b*) The space vehicle has a rocket engine which produces a constant thrust of 1000 N. The space probe has a rocket engine which produces a constant thrust of 500 N.

The space vehicle and space probe are now brought to rest from their combined speed of $0{\cdot}20\,\text{m s}^{-1}$.

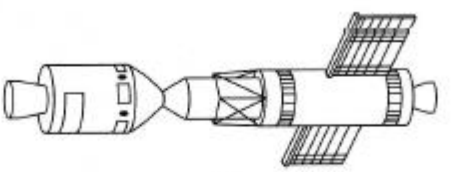
(i) Which rocket engine was switched on to bring the vehicle and probe to rest?

(ii) Calculate the time for which this rocket engine was switched on. You may assume that a negligible mass of fuel was used during this time. **3**

(*c*) The space vehicle and space probe are to be moved from their stationary position at A and brought to rest at position B, as shown.



A



B

Explain clearly how the rocket engines of the space vehicle and the space probe are used to complete this manoeuvre.

Your explanation must include an indication of the relative time for which each rocket engine must be fired.

You may assume that a negligible mass of fuel is used during this manoeuvre. **2**

(7)

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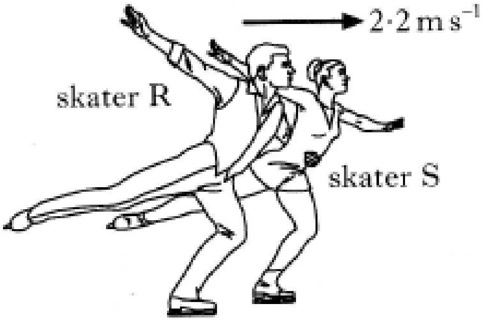
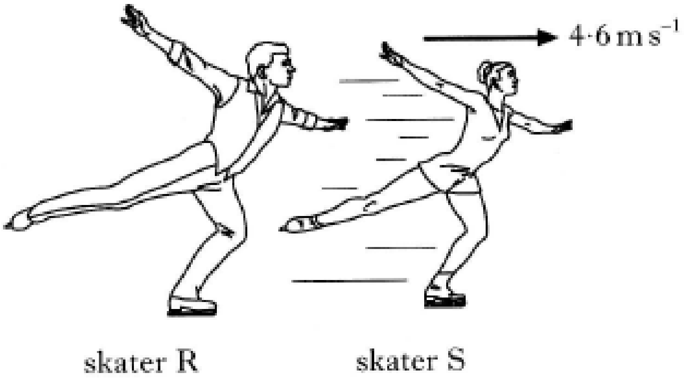
22. Two ice skaters are initially skating together, each with a velocity of $2 \cdot 2\,m\,s^{-1}$ to the right as shown.



The mass of skater R is 54 kg. The mass of skater S is 38 kg.

Skater R now pushes skater S with an average force of 130 N for a short time. This force is in the same direction as their original velocity.

As a result, the velocity of skater S increases to $4 \cdot 6\,m\,s^{-1}$ to the right.



(*a*) Calculate the magnitude of the change in momentum of skater S. **2**

(*b*) How long does skater R exert the force on skater S? **2**

(*c*) Calculate the velocity of skater R immediately after pushing skater S. **2**

(*d*) Is this interaction between the skaters elastic?

You must justify your answer by calculation. **3**

(9)

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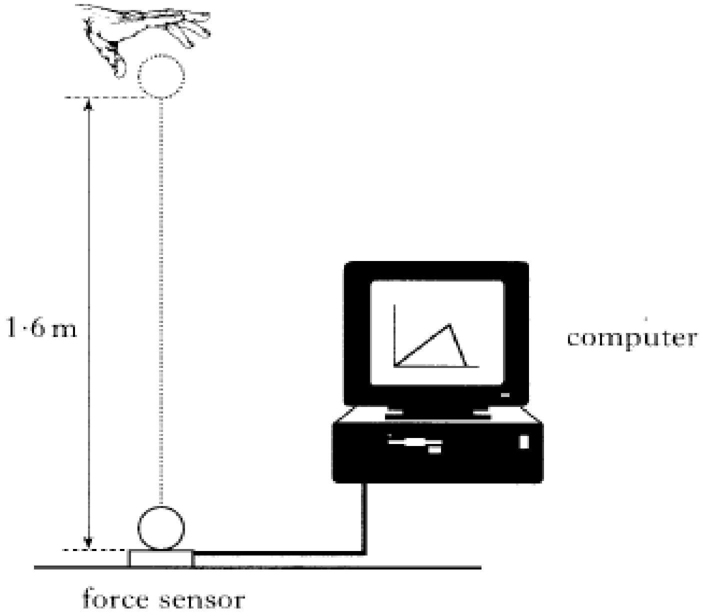
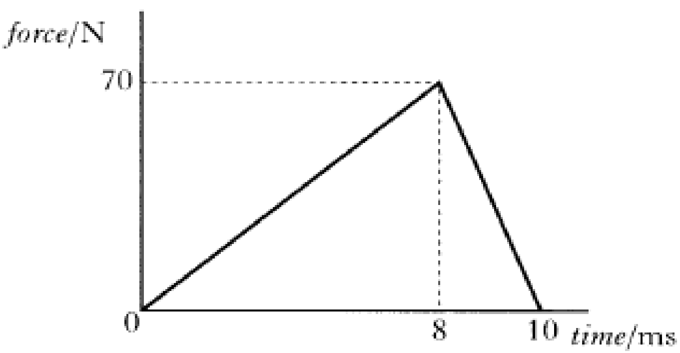
22. A force sensor is used to investigate the impact of a ball as it bounces on a flat horizontal surface. The ball has a mass of 0·050 kg and is dropped vertically, from rest, through a height of 1·6 m as shown.



(*a*) The graph shows how the force on the ball varies with time during the impact.



(i) Show by calculation that the magnitude of the impulse on the ball is 0·35 N s. **1**

(ii) What is the magnitude and direction of the change in momentum of the ball? **1**

(iii) The ball is travelling at $5{\cdot}6\ \text{m s}^{-1}$ just before it hits the force sensor. Calculate the speed of the ball just as it leaves the force sensor. **2**

(*b*) Another ball of identical size and mass, but made of a harder material, is dropped from rest and from the same height onto the same force sensor. Sketch the force-time graph shown above and, on the same axes, sketch another graph to show how the force on the harder ball varies with time.

Numerical values are not required but you must label the graphs clearly. **2**

(6)

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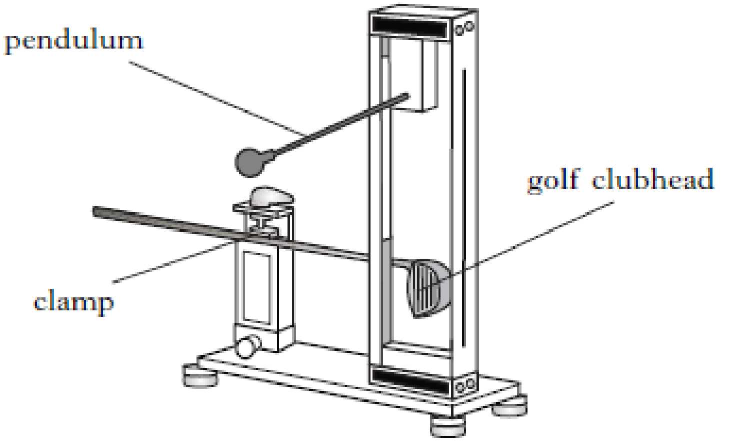
22. Golf clubs are tested to ensure they meet certain standards.

(*a*) In one test, a securely held clubhead is hit by a small steel pendulum. The time of contact between the clubhead and the pendulum is recorded.



The experiment is repeated several times.

The results are shown.

248 µs 259 µs 251 µs 263 µs 254 µs

(i) Calculate:

(A) the mean contact time between the clubhead and the pendulum; **1**

(B) the approximate absolute random uncertainty in this value. **1**

(ii) In this test, the standard required is that the maximum value of the mean contact time must not be greater than 257 µs.

Does the club meet this standard?

You must justify your answer. **1**

(*b*) In another test, a machine uses a club to hit a stationary golf ball.

The mass of the ball is $4{\cdot}5 \times 10^{-2}$ kg. The ball leaves the club with a speed of $50{\cdot}0\,\mathrm{m\,s^{-1}}$. The time of contact between the club and ball is 450 µs.

(i) Calculate the average force exerted on the ball by the club. **2**

(ii) The test is repeated using a different club and an identical ball. The machine applies the same average force on the ball but with a longer contact time.

What effect, if any, does this have on the speed of the ball as it leaves the club?

Justify your answer. **2**

(7)

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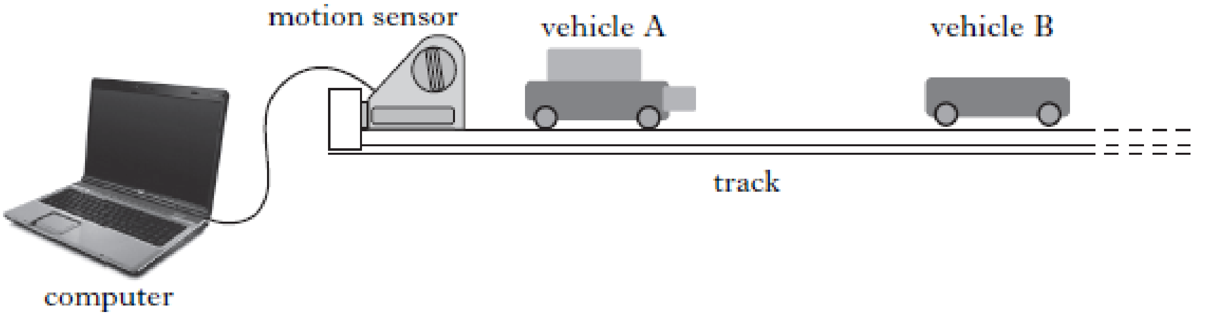
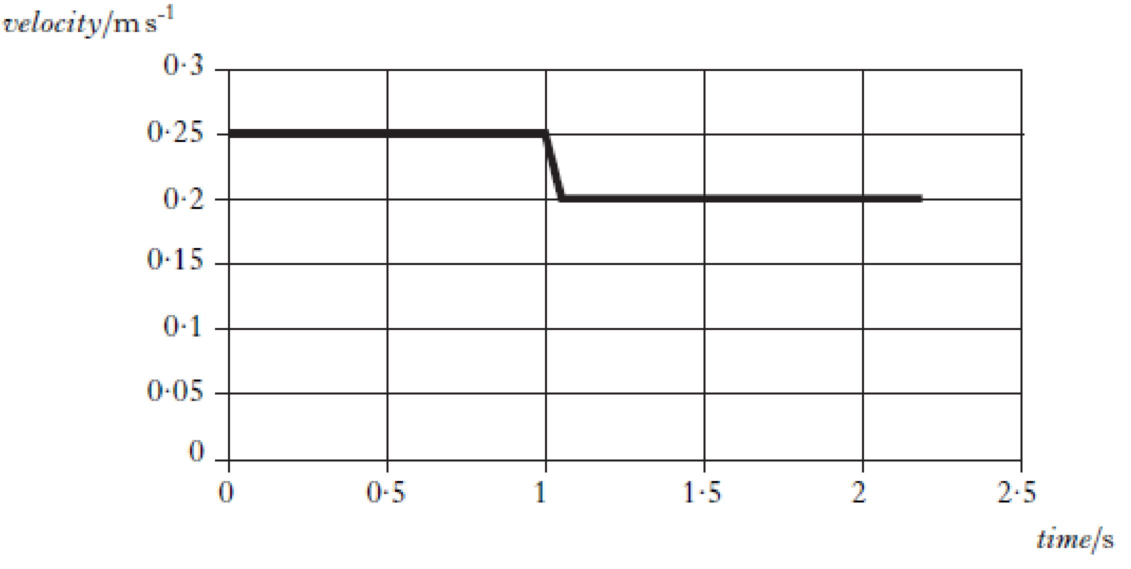
22. The apparatus shown is set up to investigate collisions between two vehicles on a track.



The mass of vehicle A is 0·22 kg and the mass of vehicle B is 0·16 kg.

The effects of friction are negligible.

(*a*) During one experiment the vehicles collide and stick together. The computer connected to the motion sensor displays the velocity-time graph for vehicle A.



(i) State the law of conservation of momentum. **1**

(ii) Calculate the velocity of vehicle B before the collision. **2**

(*b*) The same apparatus is used to carry out a second experiment.

In this experiment, vehicle B is stationary before the collision.

Vehicle A has the same velocity before the collision as in the first experiment.

After the collision, the two vehicles stick together.

Is their combined velocity less than, equal to, or greater than that in the first collision?

Justify your answer. **2**

(5)

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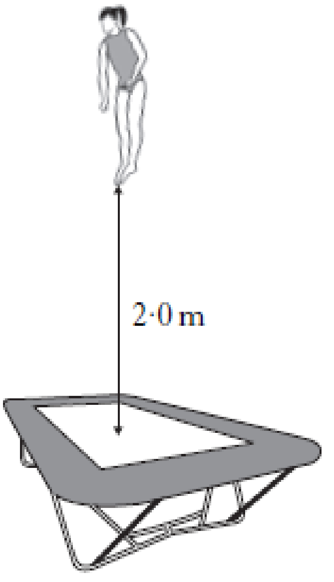
23. (*a*) A gymnast of mass 40 kg is practising on a trampoline.



(i) At maximum height the gymnast's feet are 2·0 m above the trampoline. Show that the speed of the gymnast, as she lands on the trampoline, is 6·3 m s^{-1}. **1**

(ii) The gymnast rebounds with a speed of 5·7 m s^{-1}. Calculate the change in momentum of the gymnast. **2**

(iii) The gymnast was in contact with the trampoline for 0·50 s. Calculate the average force exerted by the trampoline on the gymnast. **2**

(5)

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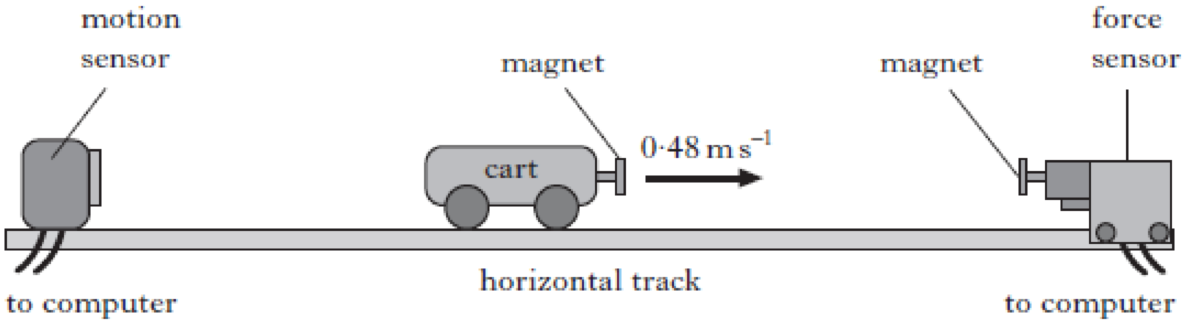
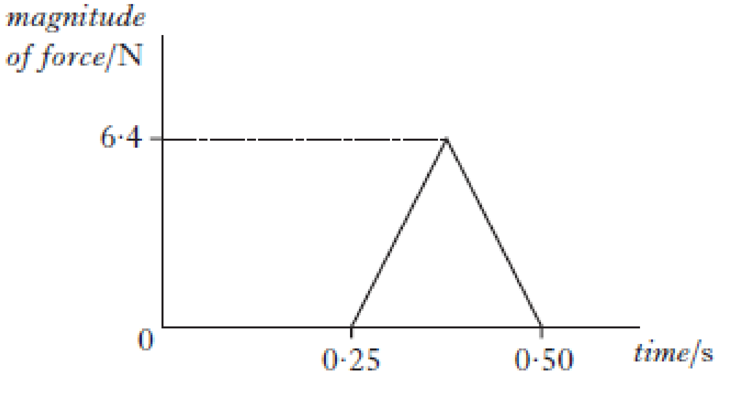
22. An experiment is set up to investigate the motion of a cart as it collides with a force sensor.



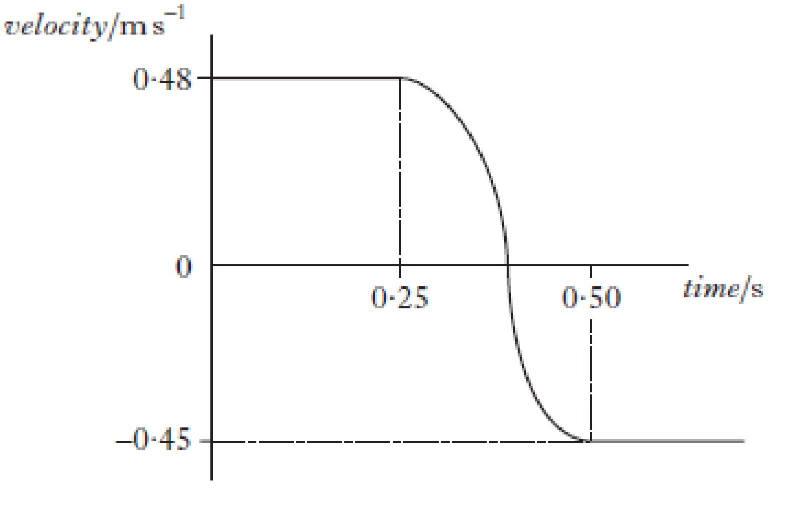
The cart moves along the horizontal track at $0 \cdot 48\,\text{m s}^{-1}$ to the right.

As the cart approaches the force sensor, the magnets repel each other and exert a force on the cart.

The computer attached to the force sensor displays the following force-time graph for this collision.



The computer attached to the motion sensor displays the following velocity-time graph for the cart.



Continued on next page

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22. (continued)

(*a*) (i) Calculate the magnitude of the impulse on the cart during the collision. **2**

(ii) Determine the magnitude and direction of the change in momentum of the cart. **1**

(iii) Calculate the mass of the cart. **2**

(*b*) The experiment is repeated using different magnets which produce a greater average force on the cart during the collision. As before, the cart is initially travelling at $0{\cdot}48\,m\,s^{-1}$ to the right and the collision causes the same change in its velocity.

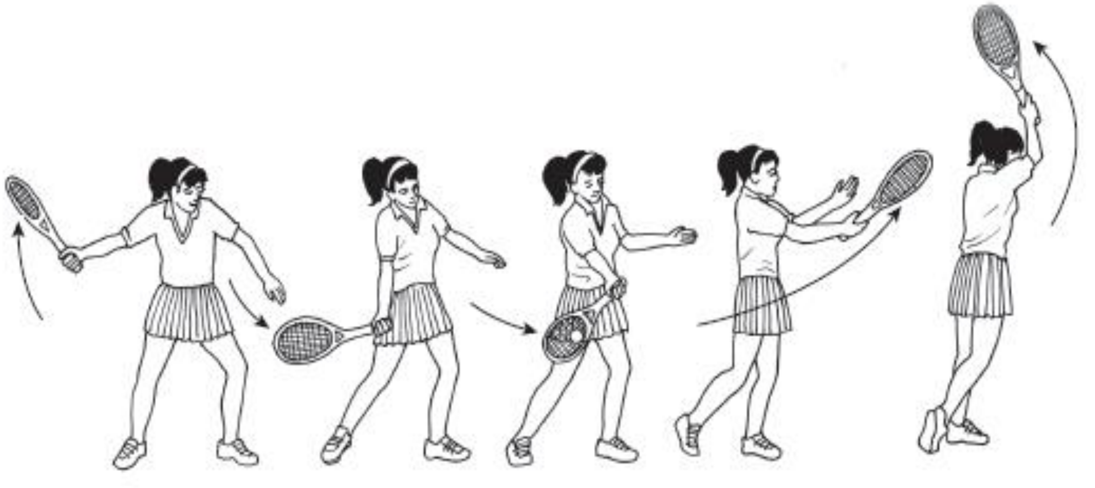
Copy the force-time graph shown and, on the same axes, draw another graph to show how the magnitude of the force varies with time in this collision.

Numerical values are not required but you must label each graph clearly. **2**

(7)

2012 Q24

24. Tennis players are coached to swing "through the ball" when striking it rather than stopping the tennis racquet suddenly.



Use your knowledge of physics to comment on why this causes the ball to leave the racquet with a greater speed. **(3)**

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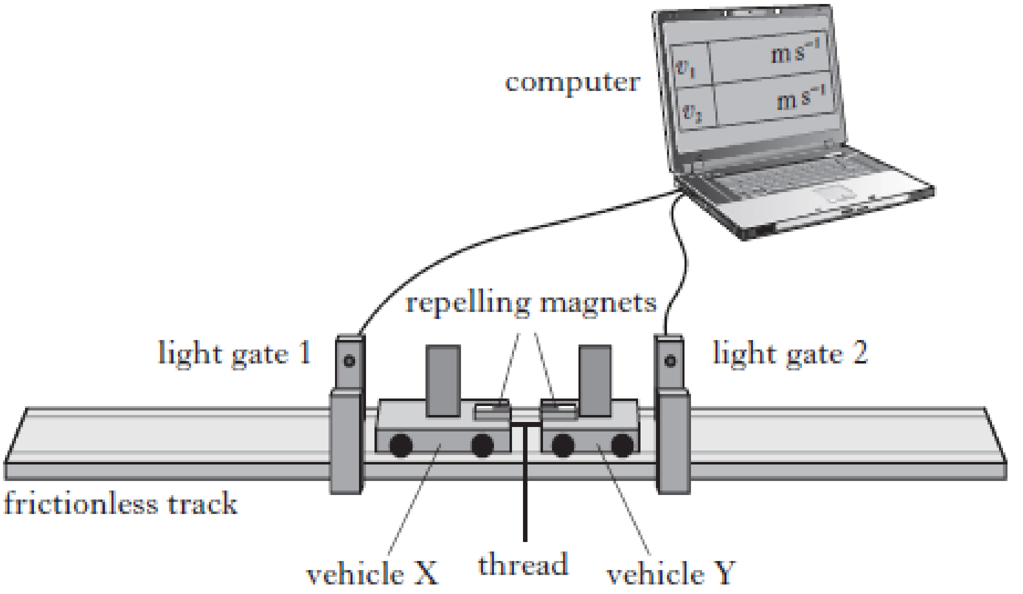
23. Interactions between objects can be analysed using the law of conservation of momentum.

(*a*) An experiment is set up to verify that momentum is conserved when two vehicles explode apart.



Initially both vehicles are stationary on the horizontal track and are held together by a thread.

The thread is cut and the force between the magnets pushes the vehicles apart.

The computer then displays the speed of each vehicle as it passes through a light gate.

The following data is recorded:

Mass of vehicle X = 0·70 kg
Mass of vehicle Y = 0·30 kg
Speed of vehicle X through light gate 1 = 0·51 m s^{-1}
Speed of vehicle Y through light gate 2 = 1·19 m s^{-1}

Use this data to show that momentum is conserved in this interaction. **2**

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Continued on next page

23. (continued)

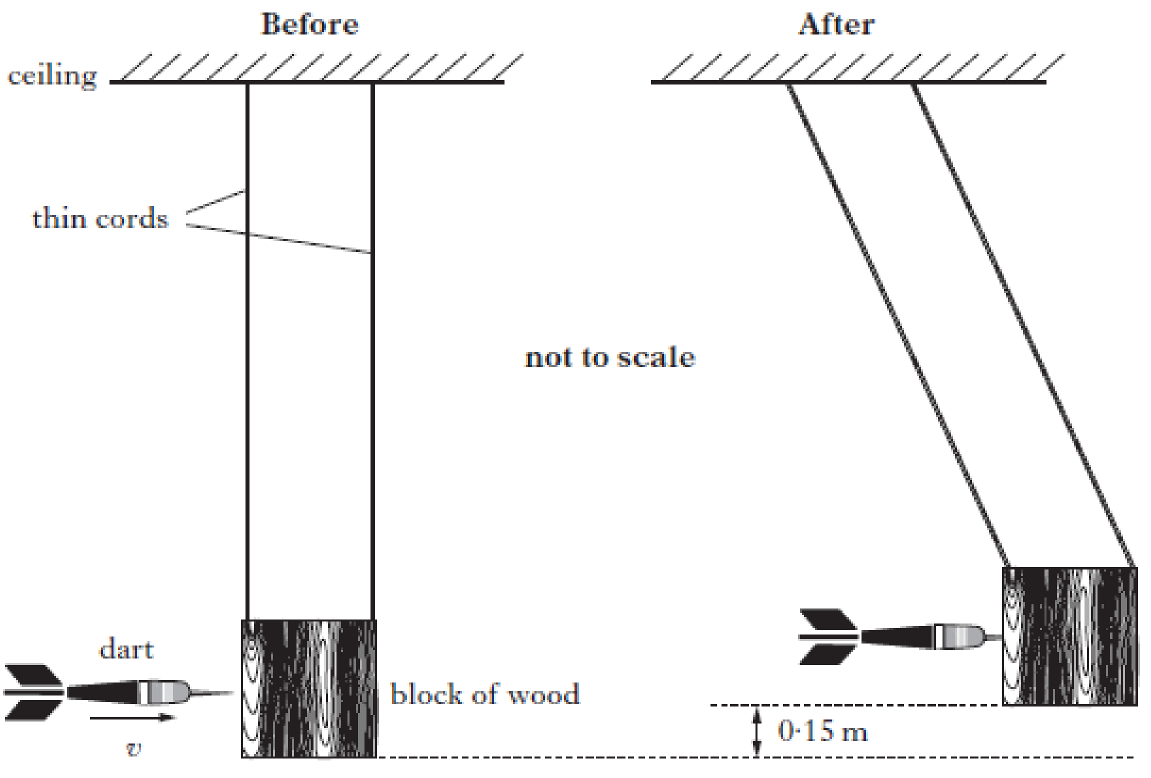
(*b*) In a second experiment, a block of wood of mass 0·20 kg is suspended from the ceiling by thin cords of negligible mass.

A dart of mass 0·050 kg is thrown at the stationary block of wood.

Just before the dart hits the block it is travelling horizontally at a velocity v.

The dart sticks into the block.

The dart and block then swing to a maximum height of 0·15 m as shown.



(i) Use conservation of energy to show that the velocity of the dart and block just after the collision is 1·7 m s^{-1}. **1**

(ii) Calculate the velocity v of the dart just before it hits the block. **2**

(iii) The experiment is repeated.

Just before it hits the block, the dart is travelling with the same velocity as in (*b*)(ii).

This time the dart bounces backwards off the block.

Explain why the block now swings to a greater vertical height. **2**

(7)

23. During a hockey match a penalty is awarded.

This gives a player a free hit at a stationary ball with only the goalkeeper between the player and the goal.

The mass of the ball is 0·16 kg.

The hockey stick is in contact with the ball for 0·020 s.

The speed of the ball immediately after impact is $39\,m\,s^{-1}$.

(*a*) (i) Calculate the average force exerted by the stick on the ball. **2**

(ii) Sketch a graph showing how the force exerted by the stick on the ball varies with time during the impact.

You may wish to use the square ruled paper provided. **1**

(*b*) The ball is replaced by a second ball with the same mass and dimensions as the first ball. However, the material of the second ball is softer.

The speed of this second ball immediately after being struck by the hockey stick is also $39\,m\,s^{-1}$.

On the graph sketched for (*a*)(ii), draw another graph to show how the force exerted on this second ball varies with time.

You must label each graph clearly. **2**

(5)

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2019

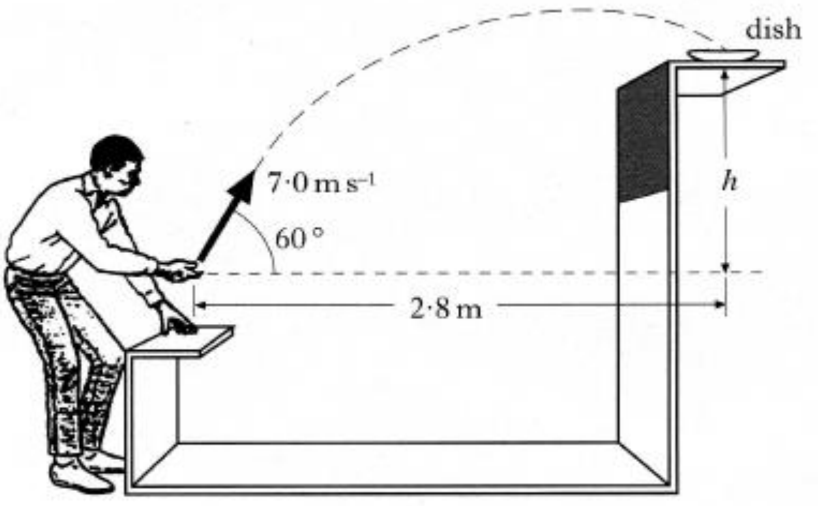
3. A footballer tells teammates that a football can be kicked a much greater distance when the ball is initially travelling towards them, compared to kicking a stationary ball.

Use your knowledge of physics to comment on this statement. 3

Gravitation - Projectiles

2000	Q21	
2003	Q21	Revised Higher
2009	Q21	
2011	Q21	
2012	Q21	Revised Higher
2012	Q33	
2015	Q21	
2016	Q21	
2017	Q3	
2018	Q4	(OPEN ENDED)
2018	Q1	

21. At a funfair, a prize is awarded if a coin is tossed into a small dish. The dish is mounted on a shelf above the ground as shown.



A contestant projects the coin with a speed of $7 \cdot 0\ \mathrm{m\,s^{-1}}$ at an angle of 60 ° to the horizontal. When the coin leaves his hand, the **horizontal distance** between the coin and the dish is 2·8 m. The coin lands in the dish.

The effect of air friction on the coin may be neglected.

(*a*) Calculate:

(i) the horizontal component of the initial velocity of the coin;

(ii) the vertical component of the initial velocity of the coin. **2**

(*b*) Show that the time taken for the coin to reach the dish is 0·8 s. **1**

(*c*) What is the height, *h*, of the shelf above the point where the coin leaves the contestant's hand? **2**

(*d*) How does the value of the kinetic energy of the coin when it enters the dish compare with the kinetic energy of the coin just as it leaves the contestant's hand?

Justify your answer. **2**

(7)

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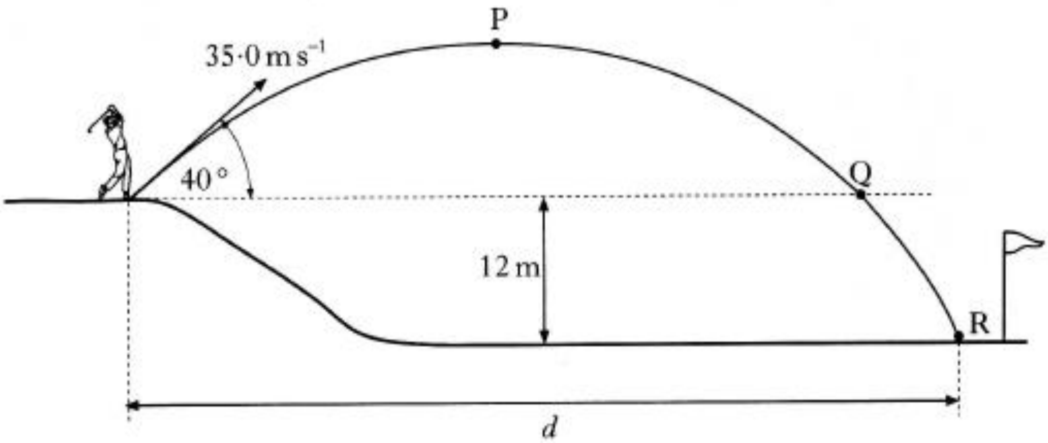
21. A golfer on an elevated tee hits a golf ball with an initial velocity of $35{\cdot}0\,m\,s^{-1}$ at an angle of 40° to the horizontal.

The ball travels through the air and hits the ground at point R.

Point R is 12 m below the height of the tee, as shown.

diagram not to scale



The effects of air resistance can be ignored.

(*a*) Calculate:

(i) the horizontal component of the initial velocity of the ball;

(ii) the vertical component of the initial velocity of the ball;

(iii) the time taken for the ball to reach its maximum height at point P. **4**

(*b*) From its maximum height at point P, the ball falls to point Q, which is at the same height as the tee.

It then takes a further 0·48 s to travel from Q until it hits the ground at R.

Calculate the total horizontal distance *d* travelled by the ball. **3**

(7)

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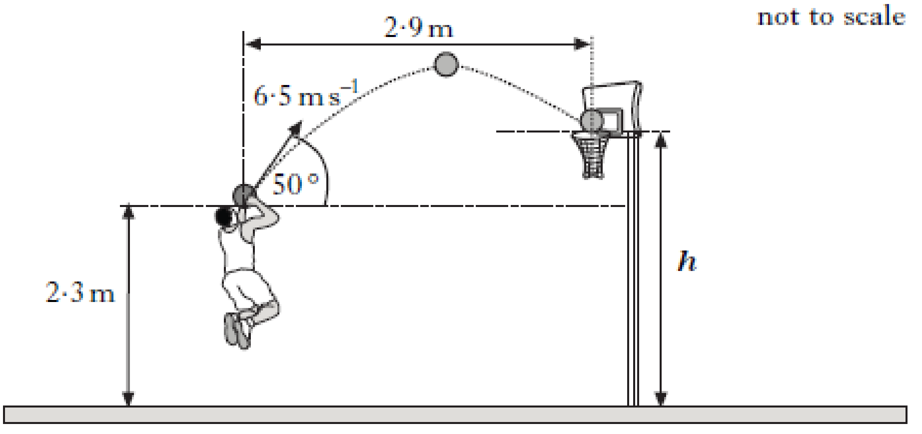
21. A basketball player throws a ball with an initial velocity of $6{\cdot}5\ \mathrm{m\,s^{-1}}$ at an angle of $50°$ to the horizontal. The ball is $2{\cdot}3$ m above the ground when released.



The ball travels a horizontal distance of $2{\cdot}9$ m to reach the top of the basket.

The effects of air resistance can be ignored.

(*a*) Calculate:

(i) the horizontal component of the initial velocity of the ball; **1**

(ii) the vertical component of the initial velocity of the ball. **1**

(*b*) Show that the time taken for the ball to reach the basket is $0{\cdot}69$ s. **1**

(*c*) Calculate the height $\boldsymbol{h}$ of the top of the basket. **2**

(*d*) A student observing the player makes the following statement.

"The player should throw the ball with a higher speed at the same angle. The ball would then land in the basket as before but it would take a shorter time to travel the 2·9 metres."

Explain why the student's statement is incorrect. **2**

(7)

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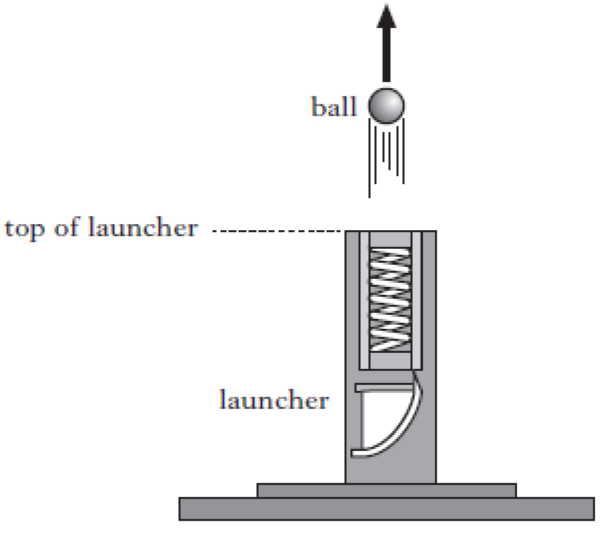
21. A student investigates the motion of a ball projected from a launcher.

The launcher is placed on the ground and a ball is fired vertically upwards.

The vertical speed of the ball as it leaves the top of the launcher is $7{\cdot}0\,m\,s^{-1}$.

The effects of air resistance can be ignored.



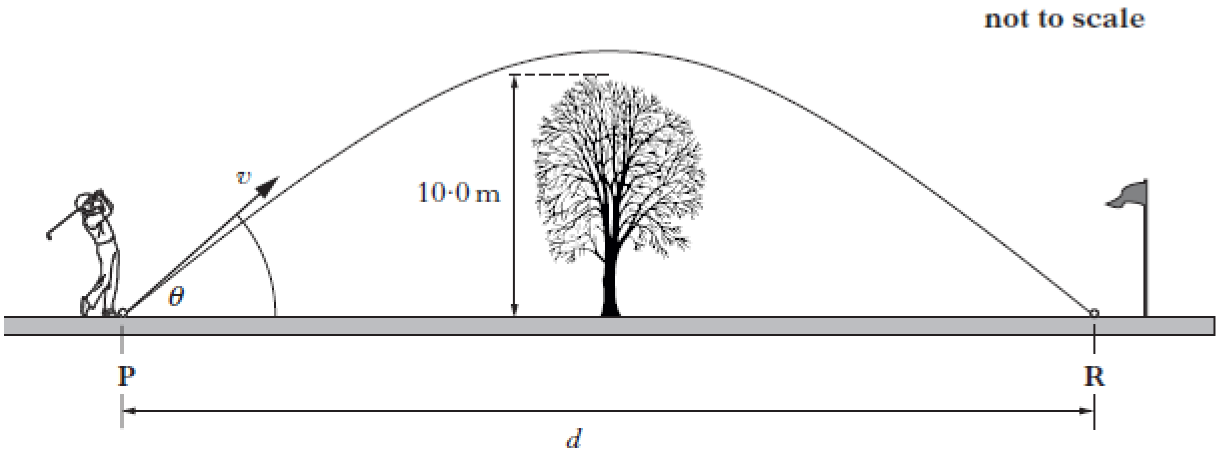
(*a*) (i) Calculate the maximum height above the top of the launcher reached by the ball. **2**

(ii) Show that the time taken for the ball to reach its maximum height is $0{\cdot}71\,s$. **1**

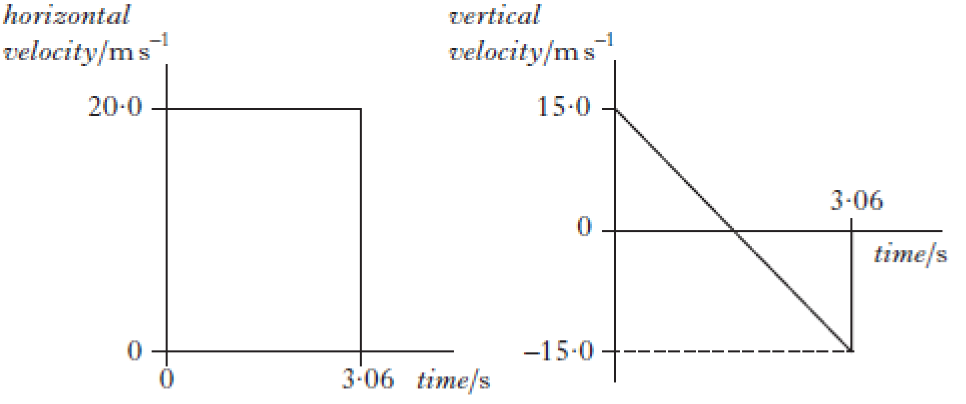
21. A golfer hits a ball from point **P**. The ball leaves the club with a velocity v at an angle of θ to the horizontal.

The ball travels through the air and lands at point **R**.

Midway between **P** and **R** there is a tree of height 10·0 m.



(*a*) The horizontal and vertical components of the ball's velocity during its flight are shown.



The effects of air resistance can be ignored.

Calculate:

(i) the horizontal distance d; **1**

(ii) the maximum height of the ball above the ground. **2**

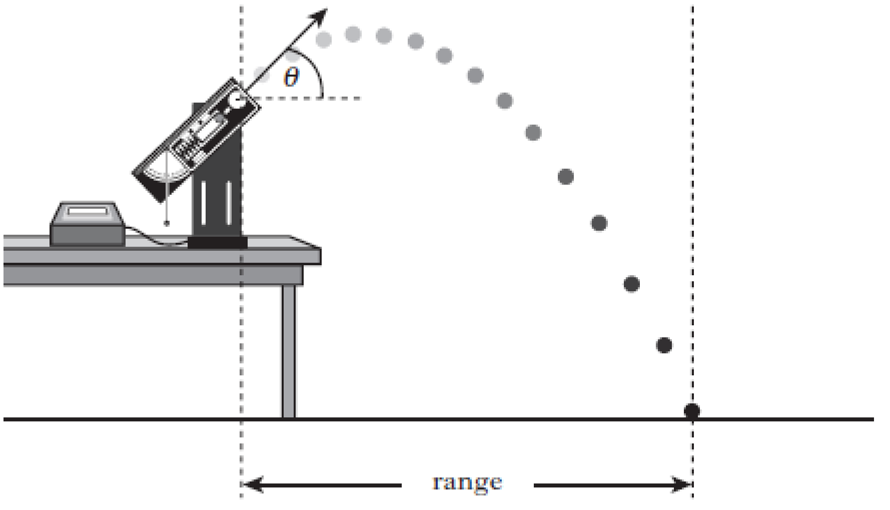
(*b*) When the effects of air resistance are **not** ignored, the golf ball follows a different path.

Is the ball more or less likely to hit the tree?

You must justify your answer. **2**

33. A group of students carries out an experiment to find how the horizontal range of a ball depends on the angle of launch, θ.

They use a projectile launcher as shown.



The results are shown in the table.

Angle of launch, θ (°)	*Range* (m)
20	1·55
30	1·64
40	1·63
50	1·43
60	1·18
70	0·95

(*a*) Using the square ruled paper provided, draw a graph of these results. **2**

(*b*) Use your graph to estimate the angle of launch that produces the maximum range of the ball. **1**

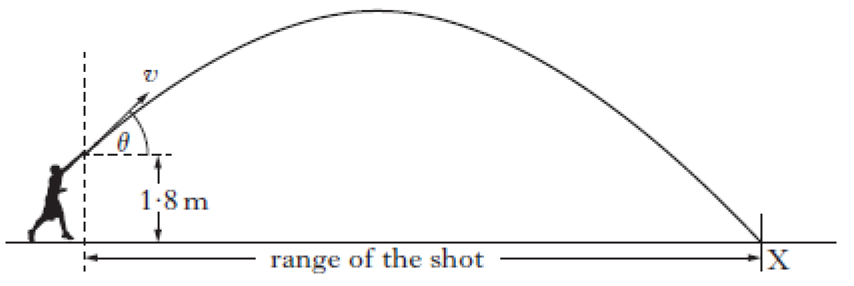
(*c*) Using the same apparatus, the students now wish to determine more precisely the angle of launch that produces the maximum range.

Suggest **two** improvements to the experimental procedure that would achieve this. **2**

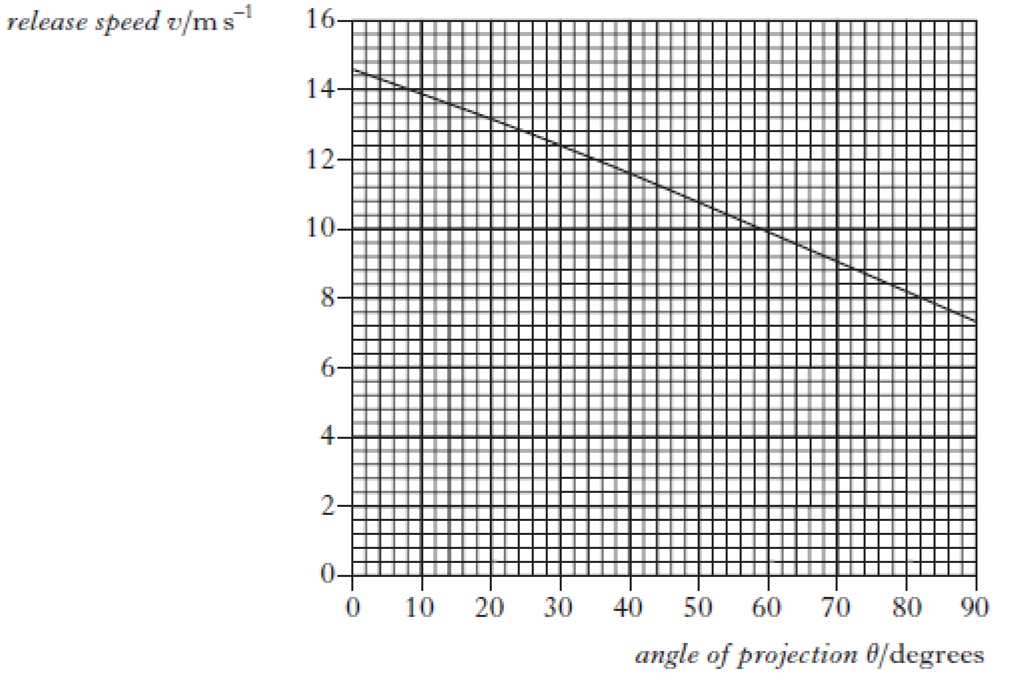
(*d*) Describe further experimental work that could be carried out to investigate another factor that may affect the horizontal range of a projectile. **2**

(7)

21. The shot put is an athletics event in which competitors "throw" a shot as far as possible. The shot is a metal ball of mass 4·0 kg. One of the competitors releases the shot at a height of 1·8 m above the ground and at an angle θ to the horizontal. The shot travels through the air and hits the ground at X.



The graph shows how the release speed of the shot v varies with the angle of projection θ.



(*a*) The angle of projection for a particular throw is 40°.

(i) (A) State the release speed of the shot at this angle. **1**

(B) Calculate the horizontal component of the initial velocity of the shot. **1**

(C) Calculate the vertical component of the initial velocity of the shot. **1**

Continued on next page

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2015 Q21

21. (a) (continued)

(ii) The maximum height reached by the shot is 4·7 m above the ground. The time between release and reaching this height is 0·76 s.

(A) Calculate the total time between the shot being released and hitting the ground. **2**

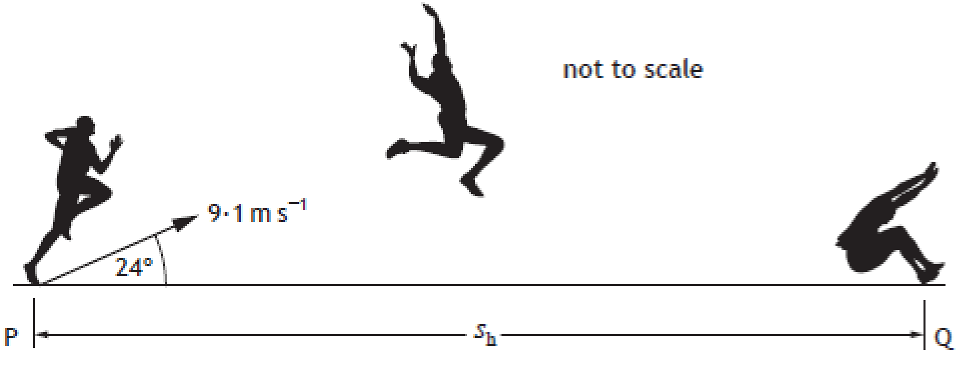
(B) Calculate the range of the shot for this throw. **2**

(b) Using information from the graph, explain the effect of increasing the angle of projection on the kinetic energy of the shot at release. **1**

(8)

2016 Q1

1.



An athlete takes part in a long jump competition. The athlete takes off from point P with an initial velocity of $9 \cdot 1\ m\ s^{-1}$ at an angle of 24° to the horizontal and lands at point Q.

(a) Calculate:

(i) the vertical component of the initial velocity of the athlete; **1**

Space for working and answer

(ii) the horizontal component of the initial velocity of the athlete. **1**

Space for working and answer

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Continued on next page

1. (continued)

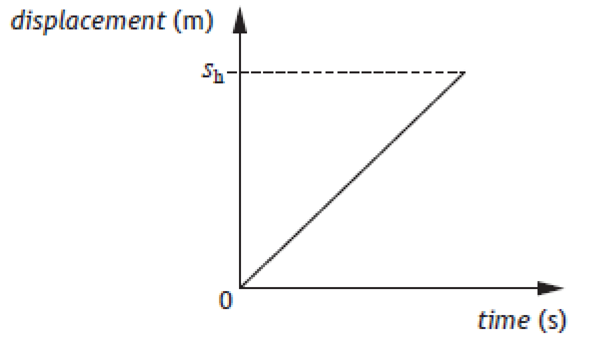
(b) Show that the time taken for the athlete to travel from P to Q is 0·76 s. **2**

Space for working and answer

(c) Calculate the horizontal displacement s_h between points P and Q. **3**

Space for working and answer

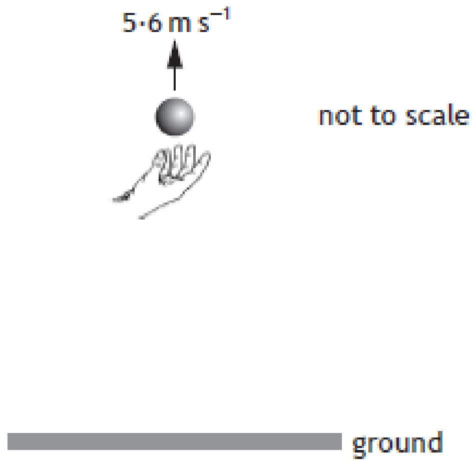
(d) The graph shows how the horizontal displacement of the athlete varies with time for this jump when air resistance is ignored.



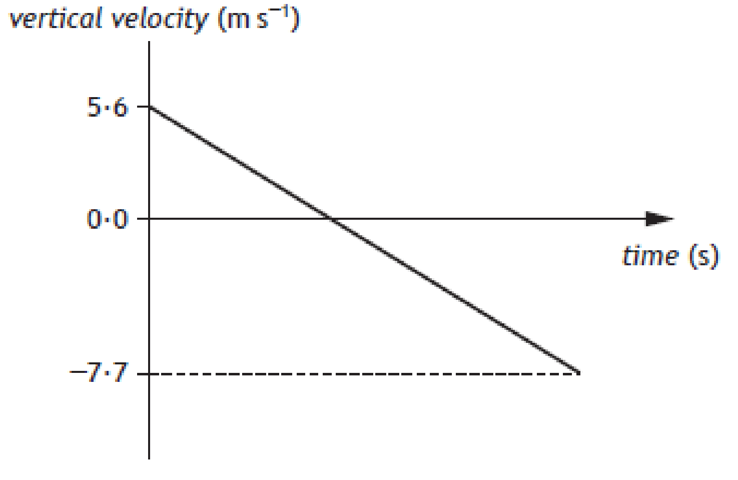
Add a line to the graph to show how the horizontal displacement of the athlete varies with time when air resistance is taken into account. **2**

3. A ball is thrown vertically upwards.

The ball is above the ground when released.



The graph shows how the vertical velocity of the ball varies with time from the instant it is released until just before it hits the ground.



The effects of air resistance can be ignored.

(a) (i) Calculate the time taken for the ball to reach its maximum height. 3

Space for working and answer

(ii) Calculate the distance the ball falls from its maximum height to the ground. 3

Space for working and answer

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Continued on next page

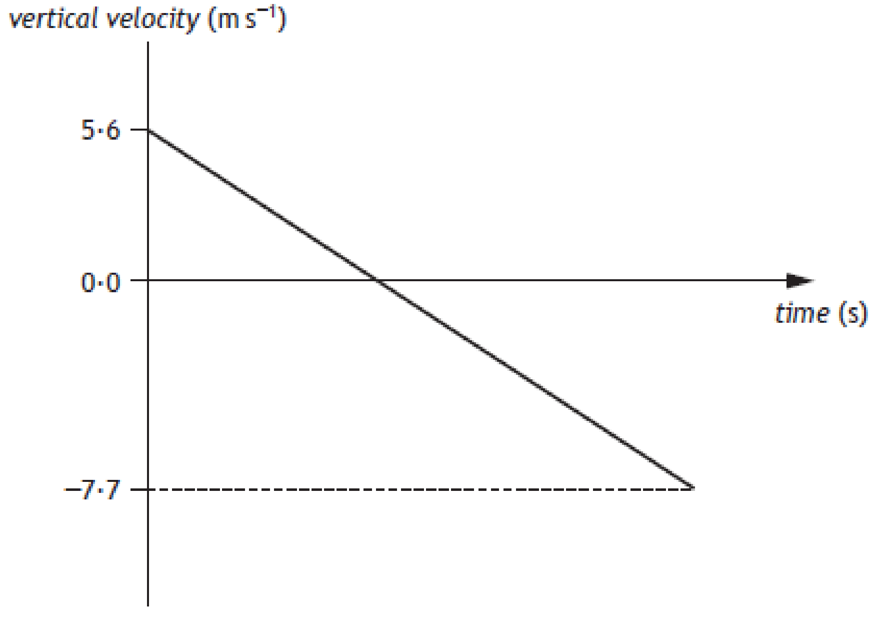
3. (continued) 2017 Q3

(b) The ball is now thrown vertically upwards from the same height with a greater initial vertical velocity.

Add a line to the graph below to show how the vertical velocity of the ball varies with time from the instant it is released until just before it hits the ground.

The effects of air resistance can be ignored.

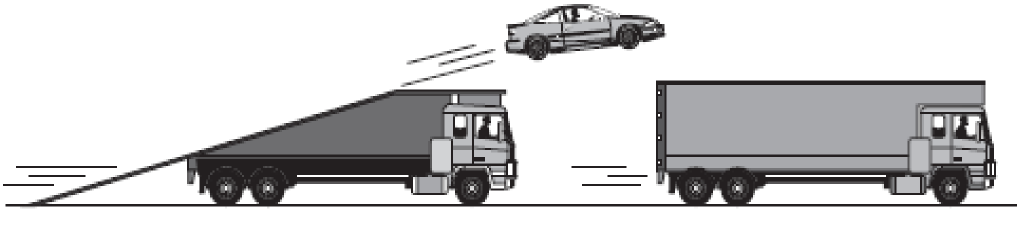
Additional numerical values on the axes are not required. 3



2018 Q4

4. A stunt is being carried out during the making of a film.

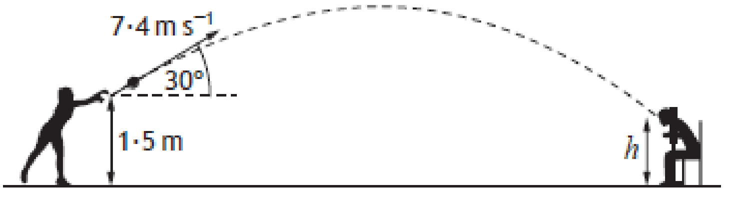
A car is to be driven up a ramp on a moving lorry by a stunt driver, who will attempt to land the car safely on the roof of a second moving lorry. The car is to stop on the roof of the second lorry while this lorry is still moving.



Using your knowledge of physics, comment on the challenges involved in carrying out the stunt successfully. 3

1. During a school funfair, a student throws a wet sponge at a teacher. The sponge is thrown with an initial velocity of $7 \cdot 4\ m\ s^{-1}$ at an angle of 30° to the horizontal.

The sponge leaves the student's hand at a height of 1·5 m above the ground.



The sponge hits the teacher.

The effects of air resistance can be ignored.

(a) (i) Calculate:

(A) the horizontal component of the initial velocity of the sponge; 1

Space for working and answer

(B) the vertical component of the initial velocity of the sponge. 1

Space for working and answer

(ii) Calculate the time taken for the sponge to reach its maximum height. 3

Space for working and answer

(iii) The sponge takes a further 0·45 s to travel from its maximum height until it hits the teacher.

Determine the height h above the ground at which the sponge hits the teacher. 4

(b) The student throwing the sponge makes the following statement.

"If the sponge is thrown with a higher speed at the same angle from the same height then it would take a shorter time to hit the teacher in the same place."

Explain why the student's statement is incorrect. 2

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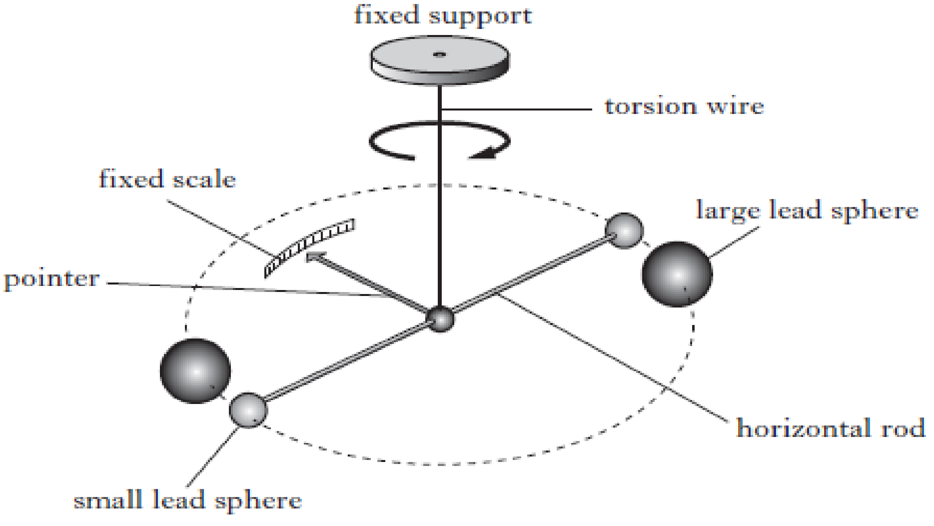
Gravitation – Universal Law

2014	Q23	Revised Higher
2017	Q5	
2019	Q4	

23. A student carries out an experiment to measure the Universal Constant of Gravitation.

The apparatus consists of a horizontal rod with small lead spheres at each end. The rod is suspended from its centre by a thin torsion wire. The student places a large lead sphere near each of the small spheres. The gravitational attraction between each pair of large and small spheres causes the torsion wire to twist. The angle of twist is indicated on a fixed scale by the position of a pointer attached to the rod.



The torsion wire twists by one degree when each small lead sphere experiences a force of $1 \cdot 56 \times 10^{-9}$ N.

(*a*) (i) The student measures the angle of twist to be $0 \cdot 45°$.

Show that the gravitational force between one pair of large and small spheres is $7 \cdot 0 \times 10^{-10}$ N. **1**

(ii) The small lead spheres each have a mass of $0 \cdot 0148$ kg.

The large lead spheres each have a mass of $1 \cdot 52$ kg.

The student measures the distance from the centre of mass of each of the large spheres to the centre of mass of its adjacent small sphere to be $46 \cdot 5$ mm.

What value does the student determine for the Universal Constant of Gravitation from these results? **2**

(*b*) The manufacturer of the apparatus claims that this experiment can achieve an accuracy to within $\pm 2 \cdot 5\%$ of the accepted value for the Universal Constant of Gravitation.

Does the student's value for the Universal Constant of Gravitation agree with this claim?

You must justify your answer by calculation. **2**

Continued on next page

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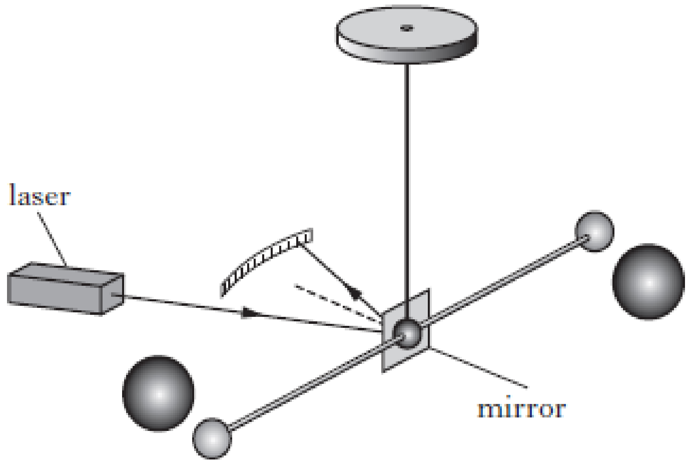
23. (continued)

(*c*) The student now decides to replace the pointer on the horizontal rod with a small mirror. A laser beam is then directed at the mirror in such a way that the beam is reflected onto the scale as shown.



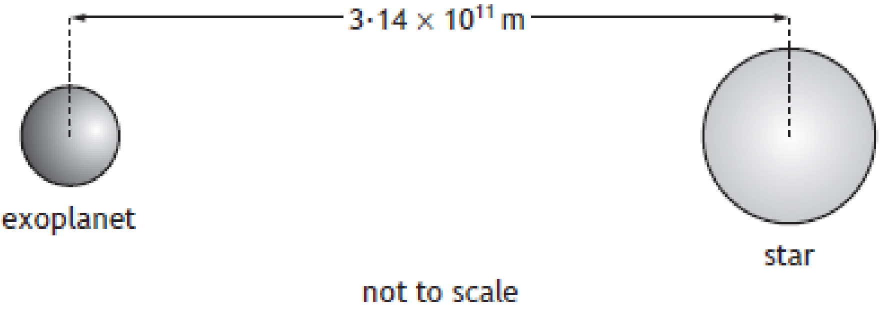
Explain how this modification improves the accuracy of the experiment. 2

(7)

2017 Q5

5. Planets outside our solar system are called exoplanets.

An exoplanet of mass $5 \cdot 69 \times 10^{27}$ kg orbits a star of mass $3 \cdot 83 \times 10^{30}$ kg.



(a) (i) Compare the mass of the star with the mass of the exoplanet in terms of orders of magnitude. 2

(ii) The distance between the exoplanet and the star is $3 \cdot 14 \times 10^{11}$ m.

Calculate the gravitational force between the star and the exoplanet. 3

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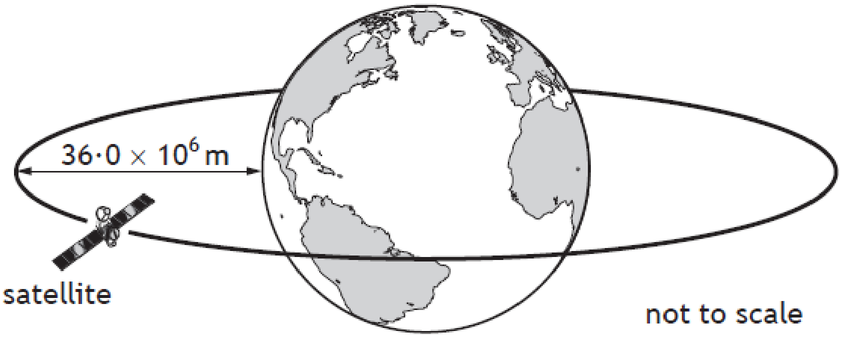
2019

4. A communications satellite orbits the Earth at a height of $36 \cdot 0 \times 10^6$ m above the surface of the Earth.



The mass of the Earth is $6 \cdot 0 \times 10^{24}$ kg and the radius of the Earth is $6 \cdot 4 \times 10^6$ m.

(a) Determine the distance between the centre of the Earth and the satellite. **1**

(b) The gravitational force of attraction between the Earth and the satellite is 57 N.

Calculate the mass of the satellite. **3**

(c) Determine the value of the Earth's gravitational field strength g at the satellite. **3**

(d) A second satellite has a **quarter** of the mass of the first satellite.

The distance from the centre of the Earth to the second satellite is **half** the distance from the centre of the Earth to the first satellite.

State how the gravitational force of attraction between the second satellite and the Earth compares to the gravitational force of attraction between the first satellite and the Earth.

Justify your answer. **3**

Relativity

2013	Q24	Revised Higher
2015	Q24	Revised Higher
2016	Q4	
2019	Q4	

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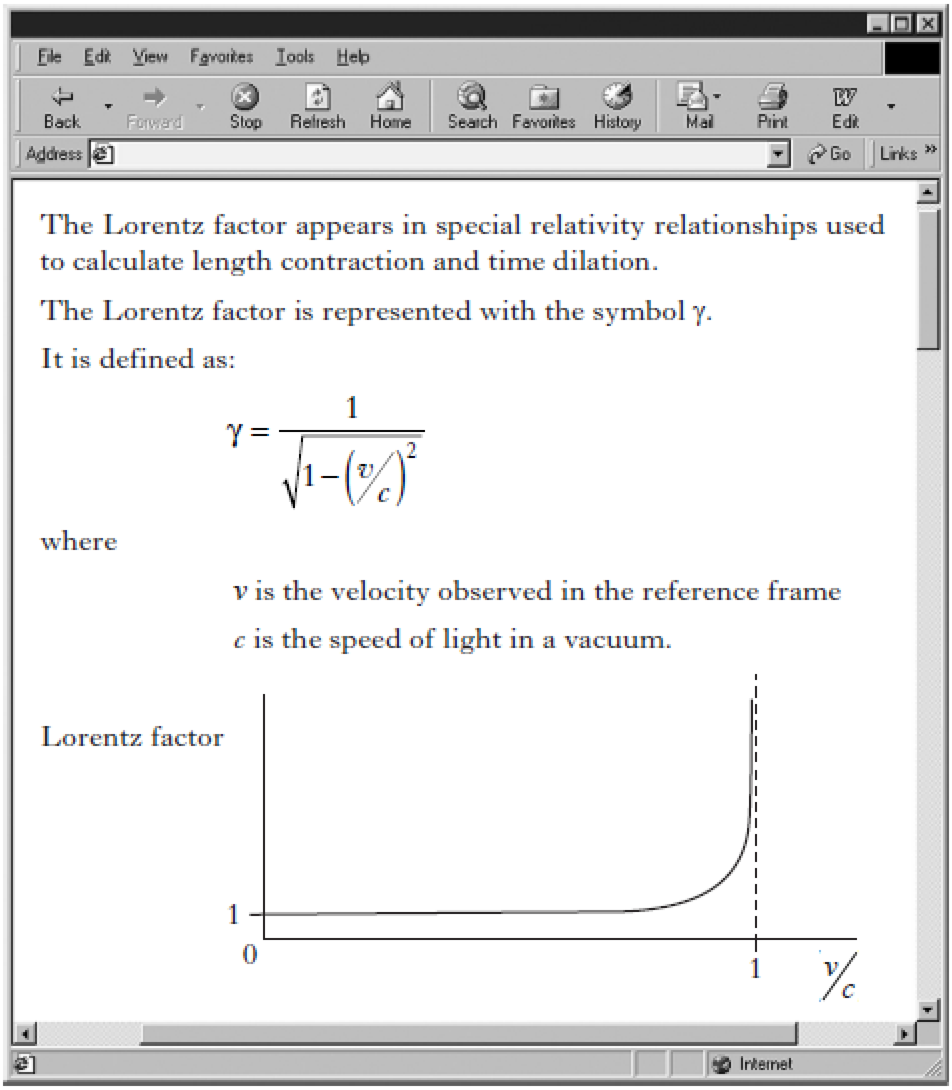
24. A page from a website on special relativity is shown.


The Lorentz factor appears in special relativity relationships used to calculate length contraction and time dilation.

The Lorentz factor is represented with the symbol γ.

It is defined as:

$$\gamma = \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$$

where

v is the velocity observed in the reference frame

c is the speed of light in a vacuum.

(*a*) Explain what is meant by the term *length contraction*. **1**

(*b*) Calculate the Lorentz factor when the ratio $\frac{v}{c}$ = 0·80. **1**

(*c*) Length contraction calculations use the relationship

$$l' = l\sqrt{1-\left(\frac{v}{c}\right)^2}$$

where the symbols have their usual meanings.

State this relationship in terms of l', l and γ. **1**

(*d*) Explain, in terms of the Lorentz factor, why an observer can ignore relativistic effects for an object which is moving with a velocity much less than c. **2**

(5)

24. A physics student notices that the digital clock in the family car loses one minute every six months.

The student states "This must be due to time dilation as the car is driven at motorway speeds for much of the time."

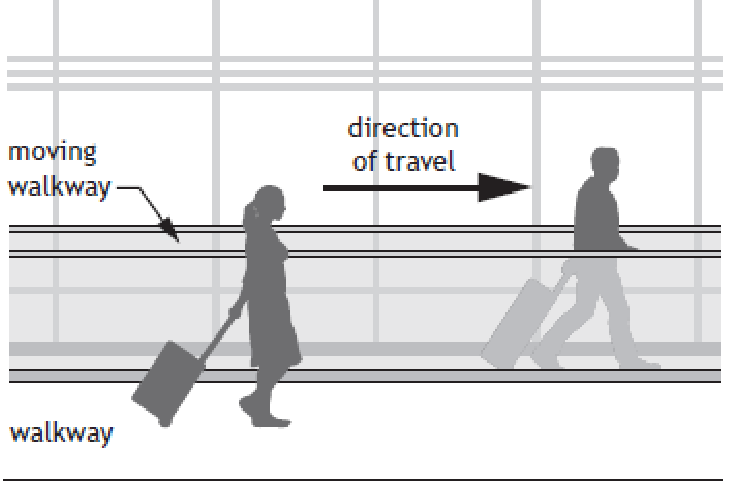
Use your knowledge of physics to comment on the student's statement. **(3)**

2016 Q4

4. Two physics students are in an airport building on their way to visit CERN.

(a) The first student steps onto a moving walkway, which is travelling at $0{\cdot}83\ \text{m s}^{-1}$ relative to the building. This student walks along the walkway at a speed of $1{\cdot}20\ \text{m s}^{-1}$ relative to the walkway.

The second student walks alongside the walkway at a speed of $1{\cdot}80\ \text{m s}^{-1}$ relative to the building.



Determine the speed of the first student relative to the second student. 2

Space for working and answer

(b) On the plane, the students discuss the possibility of travelling at relativistic speeds.

(i) The students consider the plane travelling at $0{\cdot}8c$ relative to a stationary observer. The plane emits a beam of light towards the observer.

State the speed of the emitted light as measured by the observer.

Justify your answer. 2

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Continued on next page

(ii) According to the manufacturer, the length of the plane is 71 m.

Calculate the length of the plane travelling at $0{\cdot}8c$ as measured by the stationary observer. 3

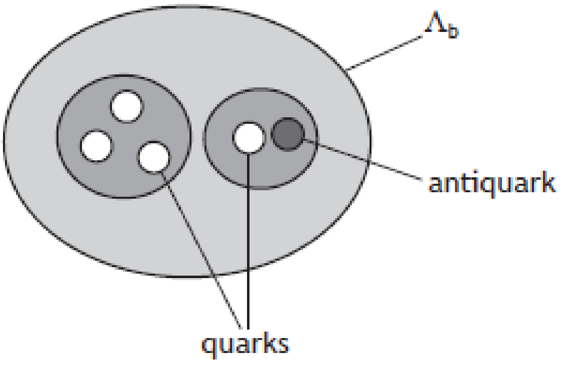
Space for working and answer

(iii) One of the students states that the clocks on board the plane will run slower when the plane is travelling at relativistic speeds.

Explain whether or not this statement is correct. 1

2019 Q4

One theory to explain the structure of the Λ_b pentaquark suggests that three of the quarks group together and one quark and the antiquark group together within the pentaquark.



(ii) The mean lifetime of another quark-antiquark pair is $8{\cdot}0 \times 10^{-21}$ s in its own frame of reference.

During an experiment the quark-antiquark pair is travelling with a velocity of $0{\cdot}91c$ relative to a stationary observer.

Calculate the mean lifetime of this quark-antiquark pair relative to the stationary observer. 3

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Expanding Universe

2012	Q22	Revised Higher
2013	Q25	Revised Higher
2014	Q24	Revised Higher
2015	Q4	
2016	Q5	
2017	Q1	
2017	Q5	
2018	Q5	
2019	Q5	
2019	Q6	

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22. All stars emit radiation with a range of wavelengths. The peak wavelength of radiation, λ_{peak}, emitted from a star is related to the surface temperature, T, of the star.

The table gives the surface temperatures, in kelvin, of four different stars and the peak wavelength radiated from each star.

Surface temperature of star T/K	*Peak wavelength radiated* λ_{peak}/m
4200	$6{\cdot}90 \times 10^{-7}$
5800	$5{\cdot}00 \times 10^{-7}$
7900	$3{\cdot}65 \times 10^{-7}$
12 000	$2{\cdot}42 \times 10^{-7}$

(*a*) Use **all** the data in the table to show that the relationship between the surface temperature, T, of a star and the peak wavelength radiated, λ_{peak}, from the star is

$$T = \frac{2{\cdot}9 \times 10^{-3}}{\lambda_{peak}}$$ **2**

(*b*) The blue supergiant star Eta Carinae is one of the largest and most luminous stars in our galaxy. It emits radiation with a peak wavelength of 76 nm.

Calculate the surface temperature, in kelvin, of this star. **2**

(*c*) Radiation of peak wavelength 1·06 mm can be detected on Earth coming from all directions in space.

(i) What name is given to this radiation? **1**

(ii) Give a reason why the existence of this radiation supports the Big Bang Theory. **1**

(6)

RH 2013 Q25

25. (*a*) Experimental work at CERN has been described as "*recreating the conditions that occurred just after the Big Bang*".

Describe what scientists mean by the *Big Bang theory* and give **one** piece of evidence which supports this theory. **2**

(*b*) During a television programme the presenter states, "*Looking through a telescope at the night sky is like looking back in time*".

Use physics principles to comment on this statement. **3**

(5)

24. According to the lyrics of a popular comedy song:

The universe itself keeps on expanding and expanding in all of the directions it can whizz.

As fast as it can go, at the speed of light, you know, twelve million miles a minute, and that's the fastest speed there is.

Use your knowledge of physics to comment on these lyrics. **(3)**

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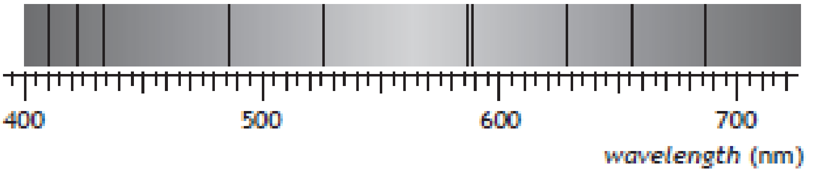
4. Light from the Sun is used to produce a visible spectrum.

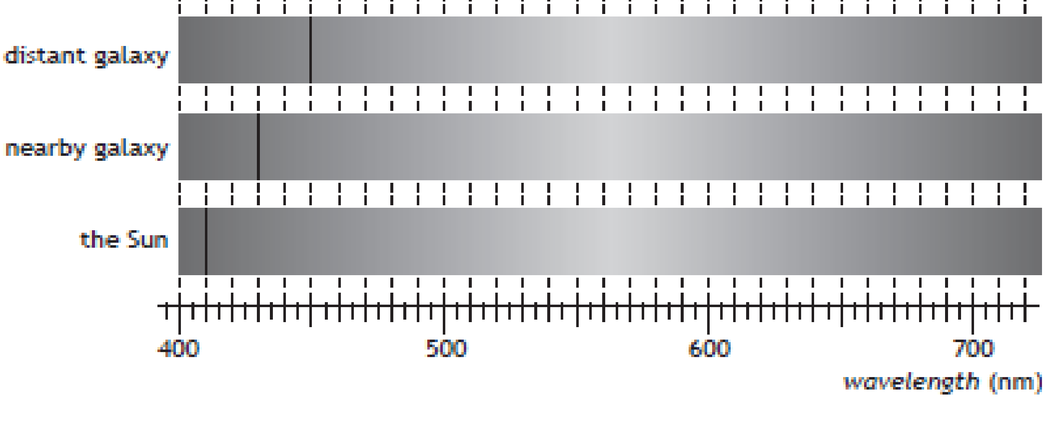
A student views this spectrum and observes a number of dark lines as shown.



(a) Explain how these dark lines in the spectrum of sunlight are produced. 2

(b) One of the lines is due to hydrogen.

The position of this hydrogen line in the visible spectrum is shown for a distant galaxy, a nearby galaxy and the Sun.



(i) Explain why the position of the line is different in each of the spectra. 2

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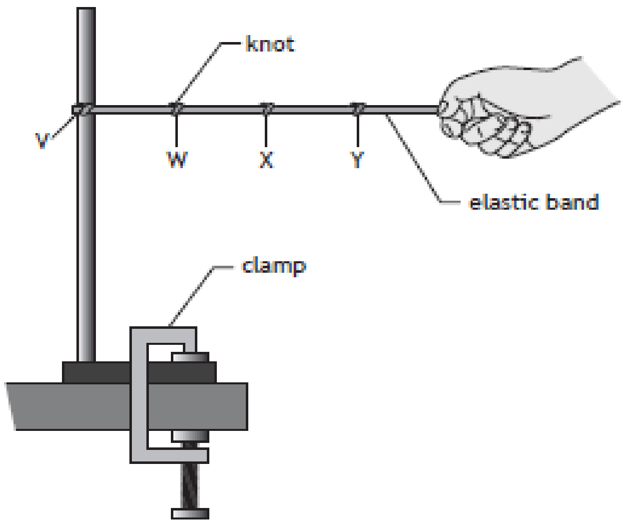
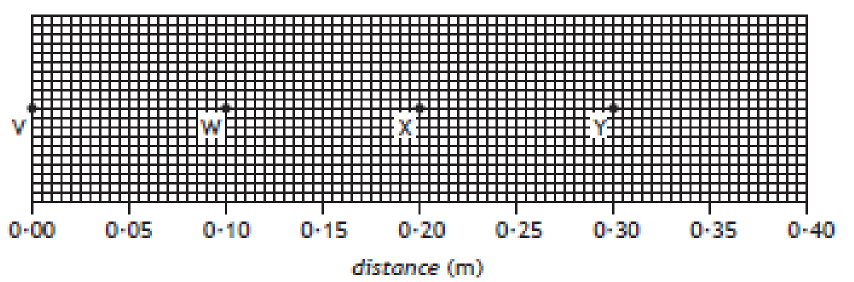
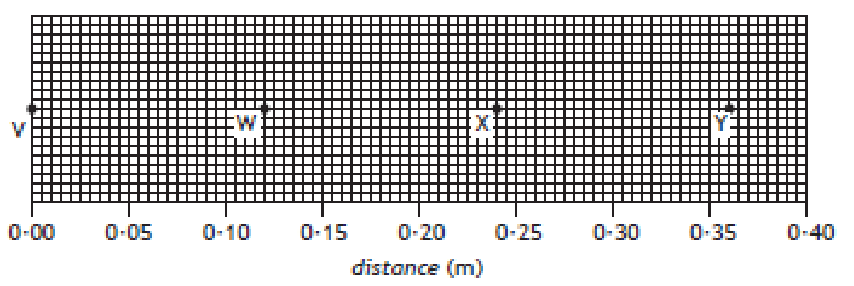
5. (a) A student is using an elastic band to model the expansion of the Universe.



One end of the band is fixed in a clamp stand at V. Knots are tied in the band to represent galaxies. The knots are at regular intervals of 0·10 m, at points W, X and Y as shown.



The other end of the elastic band is pulled slowly for 2·5 seconds, so that the band stretches. The knots are now in the positions shown below.



5. (a) (continued)

(i) Complete the table to show the average speeds of the knots X and Y. **2**

Knot	*Average speed* ($m\,s^{-1}$)
W	0·008
X	
Y	

Space for working

(ii) Explain why this model is a good simulation of the expansion of the Universe. **1**

Continued on next page

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5. (continued)

2016 Q5

(b) When viewed from the Earth, the continuous emission spectrum from the Sun has a number of dark lines. One of these lines is at a wavelength of 656 nm.

In the spectrum of light from a distant galaxy, the corresponding dark line is observed at 667 nm.

Calculate the redshift of the light from the distant galaxy. 3

Space for working and answer

---

1. (continued)

2017 Q1

(b) Later in the journey, the train is travelling at a constant speed as it approaches a bridge.

A horn on the train emits sound of frequency 270 Hz.

The frequency of the sound heard by a person standing on the bridge is 290 Hz.

The speed of sound in air is 340 m s^{-1}.

(i) Calculate the speed of the train. 3

Space for working and answer

(ii) The train continues to sound its horn as it passes under the bridge.

Explain why the frequency of the sound heard by the person standing on the bridge decreases as the train passes under the bridge and then moves away.

You may wish to use a diagram. 1

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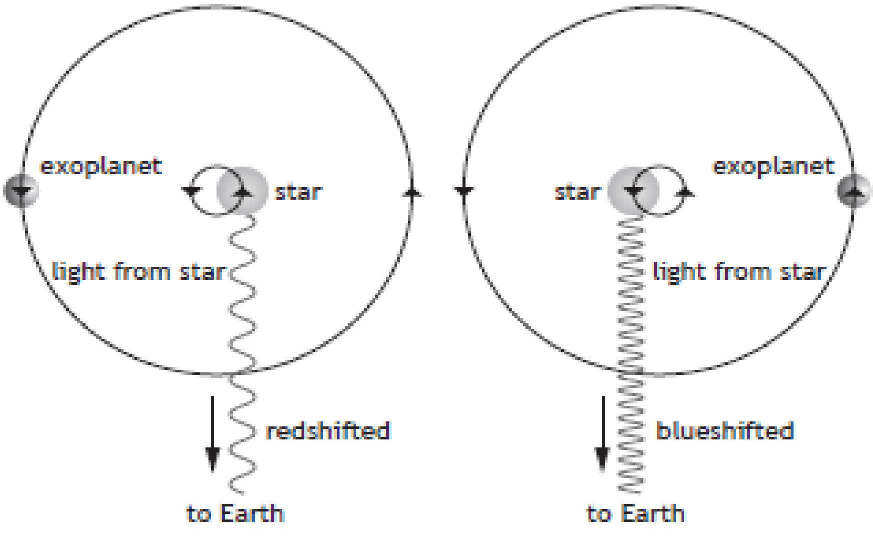
5. (continued)

(b) The gravitational force between the star and the exoplanet causes the star to follow a circular path as the exoplanet orbits the star. Small differences in the wavelength of the light from the star are observed on Earth.

Light from the star is redshifted when the star moves away from the Earth and blueshifted when the star moves towards the Earth.



(i) Calculate the redshift of light from the star observed on Earth when the star is moving away from the Earth at $6{\cdot}60 \times 10^3$ m s^{-1}. **3**

Space for working and answer

(ii) For an exoplanet of greater mass at the same distance from the star, suggest whether the radius of the circular path followed by the star would be greater than, less than, or the same as that for an exoplanet of smaller mass. **1**

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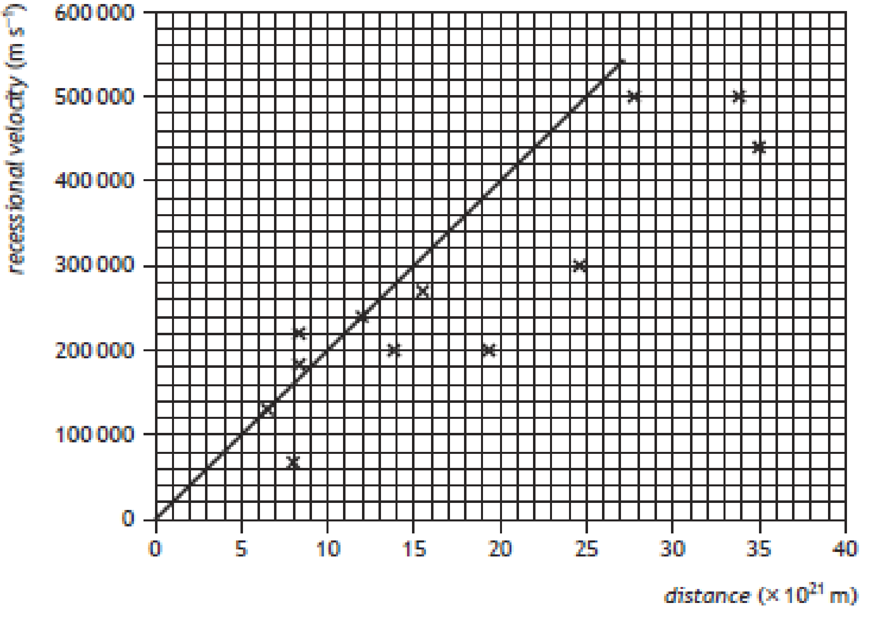
5. Hubble's Law states that the universe is expanding. The expanding universe is one piece of evidence that supports the Big Bang theory.

(a) State one other piece of evidence that supports the Big Bang theory. **1**

(b) A student plots some of the original data from the 1929 paper by Edwin Hubble and adds the line shown in order to determine a value for the Hubble constant H_0.



The student calculates the gradient of their line and obtains a value for the Hubble constant of $2{\cdot}0 \times 10^{-17}\ s^{-1}$.

The age of the universe can be calculated using the relationship

$$\text{age of universe} = \frac{1}{H_0}$$

5. (b) (continued)

(i) Calculate the age of the universe, in years, obtained when using the student's value for the Hubble constant. **2**

Space for working and answer

(ii) The current estimate for the age of the universe is $13{\cdot}8 \times 10^9$ years.

(A) State why the value obtained in (b)(i) is different from the current estimate for the age of the universe. **1**

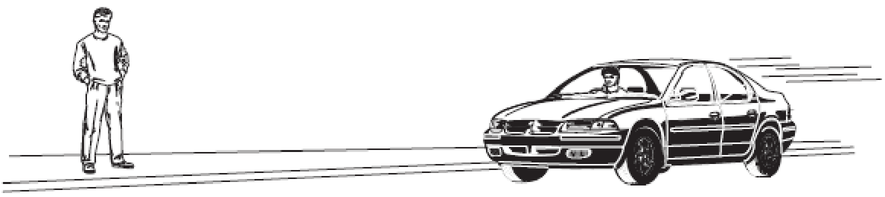
(B) Suggest a change that the student could make to their graph to obtain a value closer to the current estimate for the age of the universe. **1**

(c) It has been discovered that the rate of expansion of the universe is increasing.

State what physicists think is responsible for this increase. **1**

2019

5. (a) A person is standing at the side of a road. A car travels along the road towards the person, at a constant speed of $12\,\text{m}\,\text{s}^{-1}$. The car emits a sound of frequency 510 Hz.



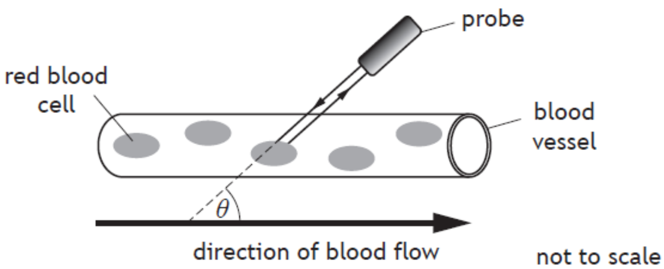
The person observes that the frequency of the sound heard changes as the car passes.

(i) State the name given to this effect. **1**

(ii) Calculate the frequency of the sound heard by the person as the car approaches.

The speed of sound in air is $340\,\text{m}\,\text{s}^{-1}$. **3**

(b) This same effect is used to determine the speed of red blood cells through blood vessels.



Ultrasound waves are transmitted by a probe. The frequency of the ultrasound waves changes as they reflect from the blood cells. The probe detects the reflected waves.

The velocity of the red blood cells can be determined using the following relationship

$$\Delta f = \frac{2f\, v_{rbc} \cos\theta}{v}$$

where Δf is the change in frequency

f is the transmitted frequency

v_{rbc} is the velocity of the red blood cells

v is the velocity of the ultrasound

θ is the angle between the direction of the waves and the direction of the blood flow.

The frequency of the ultrasound transmitted by the probe is 3·70 MHz.

The velocity of the ultrasound is $1540\,\text{m}\,\text{s}^{-1}$.

During one test, the angle between the direction of the waves and blood flow is 60·0°. The change in frequency of the ultrasound is 286 Hz.

Calculate the velocity of the red blood cells during this test. **2**

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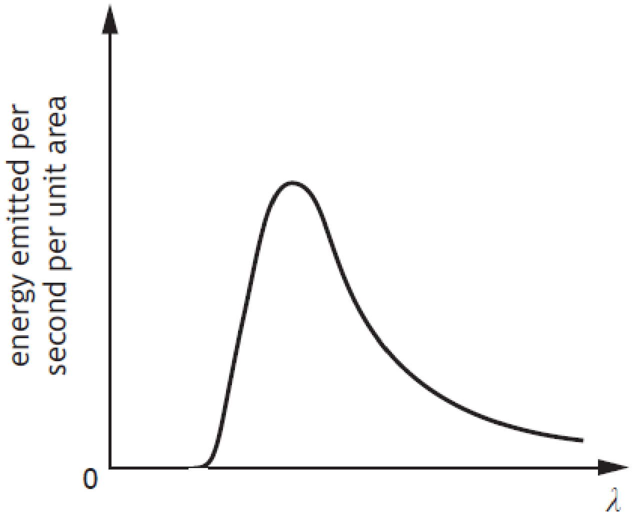
2019

6. Stars emit radiation with a range of wavelengths. The peak wavelength of the radiation depends on the surface temperature of the star.

   (a) The graph shows how the energy emitted per second per unit area varies with the wavelength λ of the radiation for a star with a surface temperature of 5000 K.



A second star has a surface temperature of 6000 K.

On the graph above, add a line to show how the energy emitted per second per unit area varies with the wavelength λ of the radiation for the second star. **2**

(b) The table gives the surface temperature T, in kelvin, of four different stars and the peak wavelength λ_{peak} of radiation emitted from each star.

T (K)	λ_{peak} (m)
7700	$3{\cdot}76 \times 10^{-7}$
8500	$3{\cdot}42 \times 10^{-7}$
9600	$3{\cdot}01 \times 10^{-7}$
12 000	$2{\cdot}42 \times 10^{-7}$

Use **all** the data in the table to show that the relationship between the surface temperature T of a star and the peak wavelength λ_{peak} radiated from the star is **3**

$$T = \frac{2\cdot9\times10^{-3}}{\lambda_{peak}}$$

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