Physics

Our Dynamic Universe

Questions and Solutions

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[HIGHER]

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Contents

Problems

Revision problems – Speed

1. The world downhill skiing speed trial takes place at Les Arcs every year. Describe a method that could be used to find the average speed of the skier over the 1 km run. Your description should include:

    (a) any apparatus required
    (b) details of what measurements need to be taken
    (c) an explanation of how you would use the measurements to carry out the calculations.

2. An athlete runs a 1500 m race in a time of 3 min 40 s. Calculate his average speed for the race.

3. It takes light 8·0 minutes to travel from the Sun to the Earth. How far away is the Sun from the Earth?
    (speed of light = $3{\cdot}0 \times 10^8$ ms^{-1}).

4. The distance between London and New York is 4800 km. A plane travels at an average speed of Mach 1·3 between London and New York.
    Calculate the time, to the nearest minute, for this journey. (Mach 1 is the speed of sound. Take the speed of sound to be 340 ms^{-1}).

5. The graph shows how the speed of a girl varies with time from the instant she starts to run for a bus.

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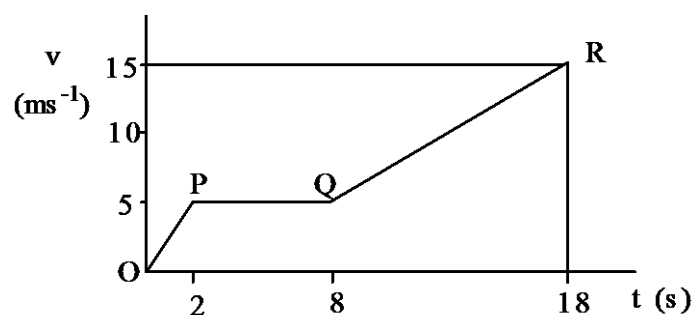
She starts from stand still at O and jumps on the bus at Q.
Find:

(a)   the steady speed at which she runs
(b)   the distance she runs
(c)   the increase in the speed of the bus while the girl is on it
(d)   how far the bus travels during QR
(e)   how far the girl travels during OR.

6.   A ground-to-air guided missile starts from rest and accelerates at 150 ms^{-2} for 5 s. What is the speed of the missile 5 s after launching?

7.   An Aston Martin has an acceleration of 6 ms^{-2} from rest. What time does it take to reach a speed of 30 ms^{-1}?

8.   A car is travelling at a speed of 34 ms^{-1}. The driver applies the brakes and the car slows down at a rate of 15 ms^{-2}. What is the time taken for the speed of the car to reduce to 4 ms^{-1}?

Revision problems – Acceleration

1.   A skateboarder starting from rest goes down a uniform slope and reaches a speed of 8 ms^{-1} in 4 s.

(a)   What is the acceleration of the skateboarder?
(b)   Calculate the time taken for the skateboarder to reach a speed of 12 ms^{-1}.

2.   In the Tour de France a cyclist is travelling at 16 ms^{-1}. When he reaches a downhill stretch he accelerates to a speed of 20 ms^{-1} in 2·0 s.

(a)   What is the acceleration of the cyclist down the hill?
(b)   The cyclist maintains this constant acceleration. What is his speed after a further 2·0 s?
(c)   How long after he starts to accelerate does he reach a speed of 28 ms^{-1}?

3. A student sets up the apparatus shown to find the acceleration of a trolley down a slope.
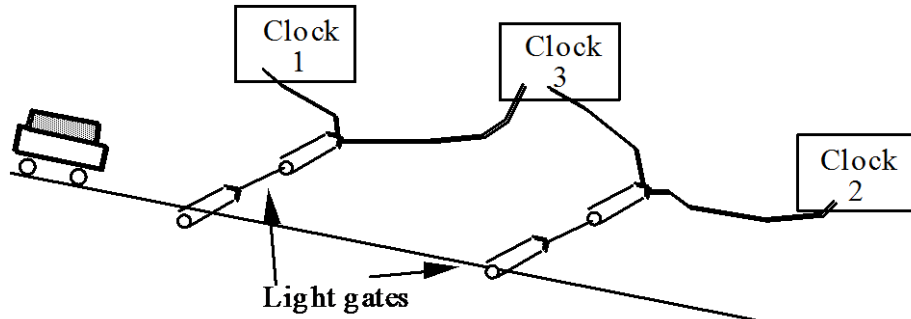
Length of card on trolley = 50 mm

Time on clock 1 = 0·10 s (time taken for card to interrupt top light gate)
Time on clock 2 = 0·05 s (time taken for card to interrupt bottom light gate)
Time on clock 3 = 2·50 s (time taken for trolley to travel between top and bottom light gate)
Use these results to calculate the acceleration of the trolley.
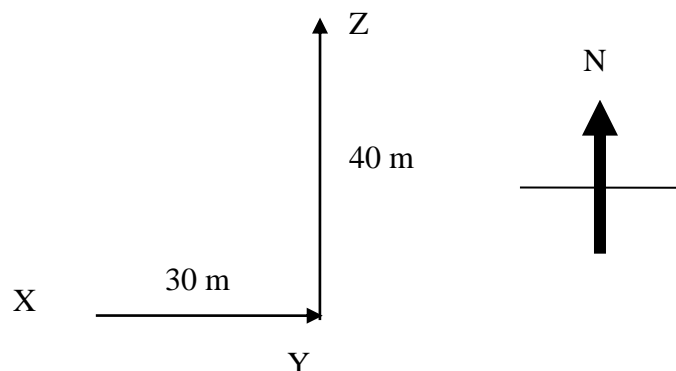
Revision problems – Vectors

1. A car travels 50 km due north and then returns 30 km due south. The whole journey takes 2 hours.

   Calculate:

   (a) the total distance travelled by the car
   (b) the average speed of the car
   (c) the resultant displacement of the car
   (d) the average velocity of the car.

2. A girl delivers newspapers to three houses, X, Y and Z, as shown in the diagram.

She starts at X and walks directly from X to Y and then to Z.

(a) Calculate the total distance the girl walks.
(b) Calculate the girl's final displacement from X.
(c) The girl walks at a steady speed of 1 ms^{-1}.
  (i) Calculate the time she takes to get from X to Z.
  (ii) Calculate her resultant velocity.

3. Find the resultant force in the following example:
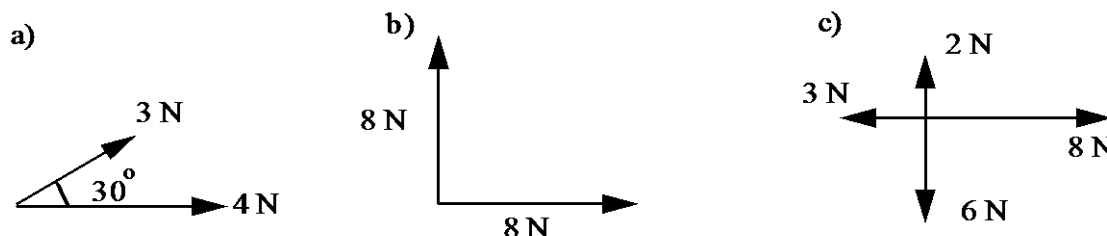
4. State what is meant by a vector quantity and scalar quantity.
   Give two examples of each.

5. An orienteer runs 5 km due south then 4 km due west and then 2 km due north. The total time taken for this is 1 hours. Calculate the average speed and average velocity of the orienteer for this run.

6. A football is kicked up at an angle of 70° at 15 ms^{-1}.

   Calculate:
   (a) the horizontal component of the velocity
   (b) the vertical component of the velocity.

Section 1: Equations of motion

Equations of motion

1. An object is travelling at a speed of $8 \cdot 0$ ms^{-1}. It then accelerates uniformly at $4 \cdot 0$ ms^{-2} for 10 s. How far does the object travel in this 10 s?

2. A car is travelling at a speed of $15 \cdot 0$ ms^{-1}. It accelerates uniformly at $6 \cdot 0$ ms^{-2} and travels a distance of 200 m while accelerating. Calculate the velocity of the car at the end of the 200 m.

3. A ball is thrown vertically upwards to a height of 40 m above its starting point. Calculate the speed at which it was thrown.

4. A car is travelling at a speed of $30 \cdot 0$ ms^{-1}. It then slows down at $1 \cdot 80$ ms^{-2} until it comes to rest. It travels a distance of 250 m while slowing down. What time does it take to travel the 250 m?

5. A stone is thrown with an initial speed $5 \cdot 0$ ms^{-1} vertically down a well. The stone strikes the water 60 m below where it was thrown. Calculate the time taken for the stone to reach the surface of the water. The effects of friction can be ignored.

6. A tennis ball launcher is $0 \cdot 60$ m long. A tennis ball leaves the launcher at a speed of 30 ms^{-1}.

    (a) Calculate the average acceleration of the tennis ball in the launcher.
    (b) Calculate the time the ball accelerates in the launcher.

7. In an experiment to find g a steel ball falls from rest through a distance of $0 \cdot 40$ *m*. The time taken to fall this distance is $0 \cdot 29$ *s*.
    What is the value of g calculated from the data of this experiment?

8. A trolley accelerates uniformly down a slope. Two light gates connected to a motion computer are spaced $0 \cdot 50$ m apart on the slope. The speeds recorded as the trolley passes the light gates are $0 \cdot 20$ ms^{-1} and $0 \cdot 50$ ms^{-1}.

(a) Calculate the acceleration of the trolley.
(b) What time does the trolley take to travel the 0·5 m between the light gates?

9. A helicopter is rising vertically at a speed of $10·0$ ms^{-1} when a wheel falls off. The wheel hits the ground $8·00$ s later.
    Calculate the height of the helicopter above the ground when the wheel came off.
    The effects of friction can be ignored.

10. A ball is thrown vertically upwards from the edge of a cliff as shown in the diagram.
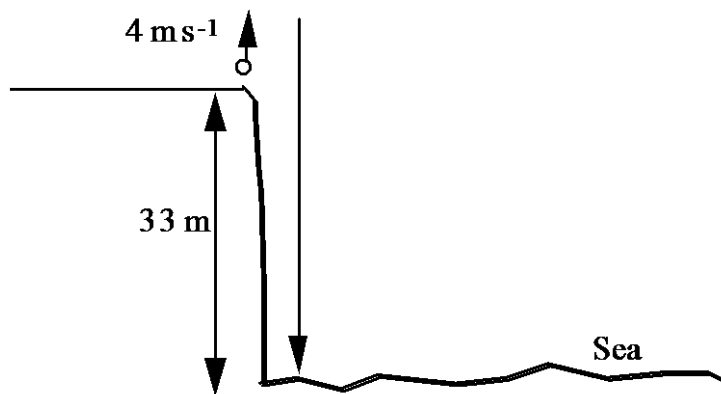
The effects of friction can be ignored.

(a) (i) What is the height of the ball above sea level 2·0 s after being thrown?
     (ii) What is the velocity of the ball 2·0 s after being thrown?

(b) What is the total distance travelled by the ball from launch to landing in the sea?

Motion – time graphs

1. The graph shows how the displacement of an object varies with time.
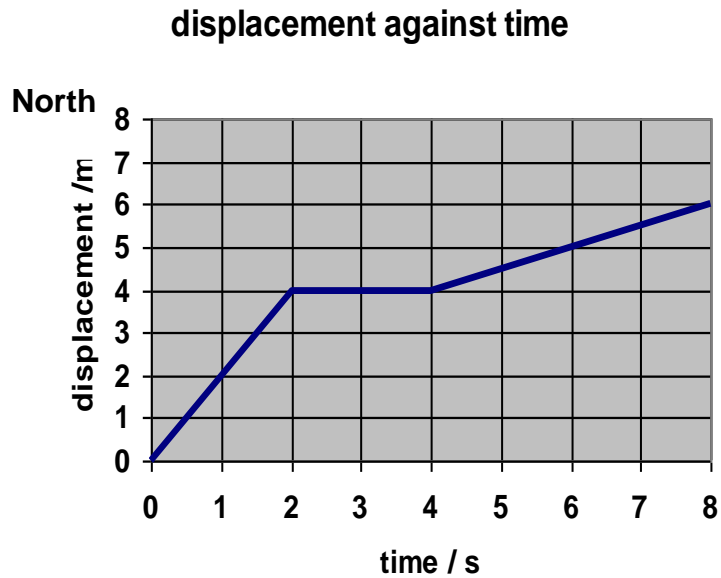
displacement against time

(a) Calculate the velocity of the object between 0 and 1 s.
(b) What is the velocity of the object between 2 and 4 s from the start?
(c) Draw the corresponding distance against time graph for the movement of this object.
(d) Calculate the average speed of the object for the 8 seconds shown on the graph.
(e) Draw the corresponding velocity against time graph for the movement of this object.¶

2. The graph shows how the displacement of an object varies with time.

displacement against time
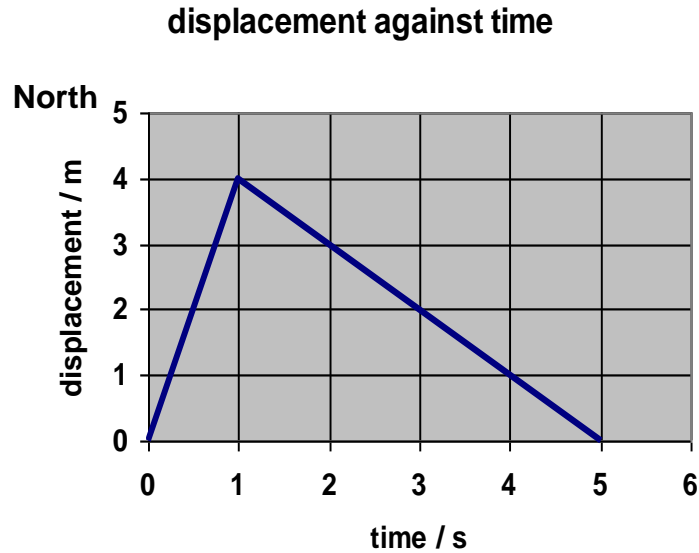
(a) Calculate the velocity of the object during the first second from the start.

(b) Calculate the velocity of the object between 1 and 5 s from the start.

(c) Draw the corresponding distance against time graph for this object.

(d) Calculate the average speed of the object for the 5 seconds.

(e) Draw the corresponding velocity against time graph for this object.

(f) What are the displacement and the velocity of the object 0·5 seconds after the start?

(g) What are the displacement and the velocity of the object 3 seconds after the start?

3.   The graph shows the displacement against time graph for the movement of an object.

displacement against time
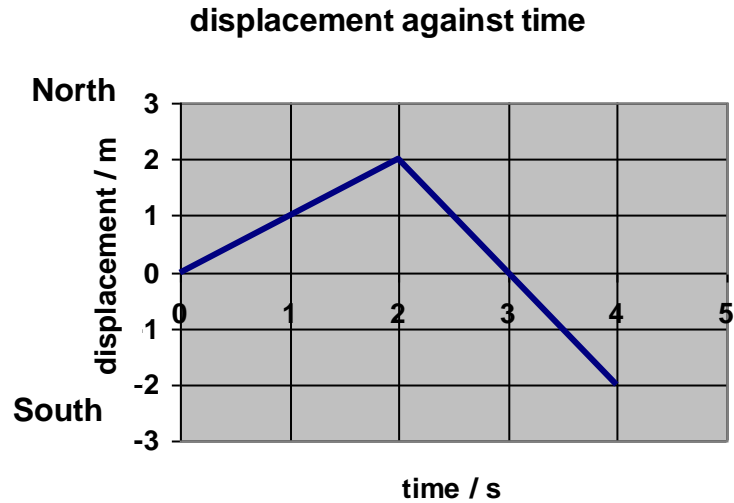
(a)   Calculate the velocity of the object between 0 and 2 s.
(b)   Calculate the velocity of the object between 2 and 4 s from the start.
(c)   Draw the corresponding distance against time graph for this object.
(d)   Calculate the average speed of the object for the 4 seconds.
(e)   Draw the corresponding velocity against time graph for this object.
(f)   What are the displacement and the velocity of the object 0·5 s after the start?
(g)   What are the displacement and the velocity of the object 3 seconds after the start?

4. An object starts from a displacement of 0 m. The graph shows how the velocity of the object varies with time from the start.

velocity against time

velocity m s⁻¹

(a) Calculate the acceleration of the object between 0 and 1 s.
(b) What is the acceleration of the object between 2 and 4 s from the start?
(c) Calculate the displacement of the object 2 seconds after the start.
(d) What is the displacement of the object 8 seconds after the start?
(e) Sketch the corresponding displacement against time graph for the movement of this object.¶

5. An object starts from a displacement of 0 m. The graph shows how the velocity of the object varies with time from the start.

velocity against time

velocity m s⁻¹

time / s

(a) Calculate the acceleration of the object between 0 and 2 s.

(b) Calculate the acceleration of the object between 2 and 4 s from the start.

(c) Draw the corresponding acceleration against time graph for this object.

(d) What are the displacement and the velocity of the object 3 seconds after the start?

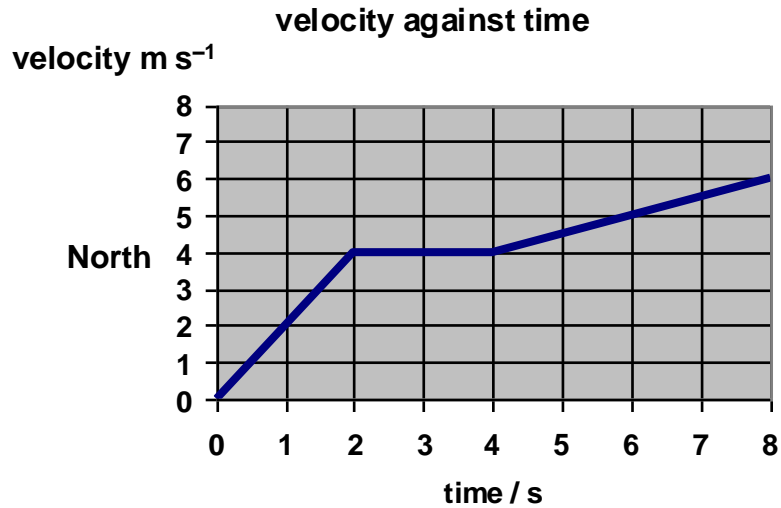(e) What are the displacement and the velocity of the object 4 seconds after the start?
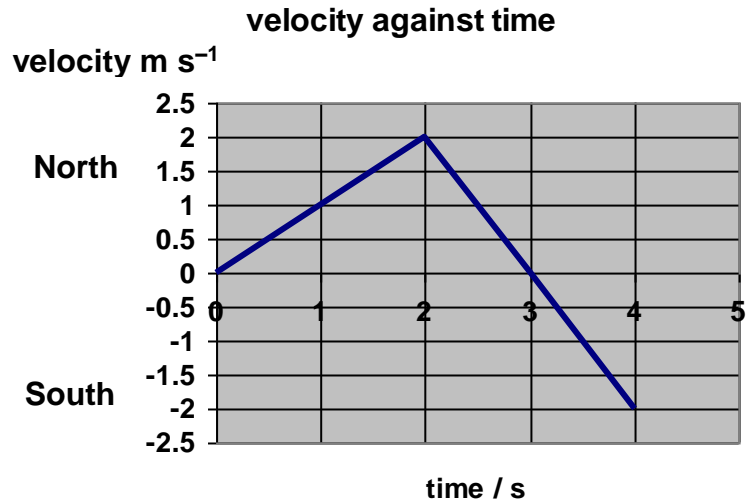
(f) Sketch the corresponding displacement against time graph for the movement of this object.

6.   The velocity-time graph for an object is shown below.

velocity against time
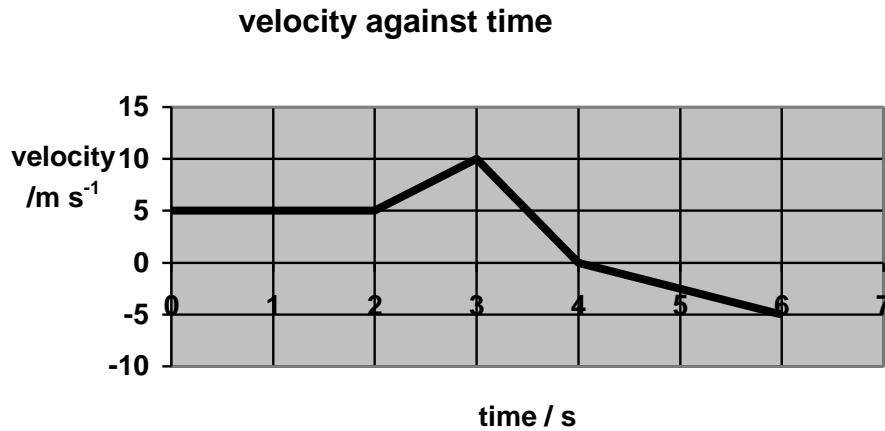
A positive value indicates a velocity due north and a negative value indicates a velocity due south. The displacement of the object is 0 at the start of timing.

(a)   Calculate the displacement of the object:
   (i)   3 s after timing starts
   (ii)   4 s after timing starts
   (iii) 6 s after timing starts.

(b)   Draw the corresponding acceleration–time graph.¶

7.   The graph shows how the acceleration *a* of an object, starting from rest, varies with time.¶
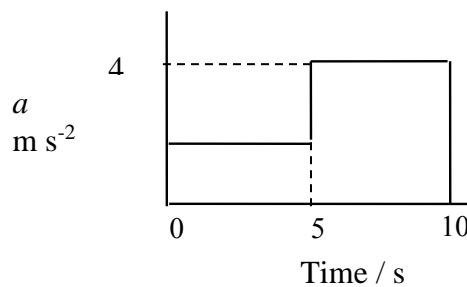
Draw a graph to show how the velocity of the object varies with time for the 10 seconds of the motion.

8. The graph shows the velocity of a ball that is dropped and bounces on a floor.
    An upwards direction is taken as being positive.
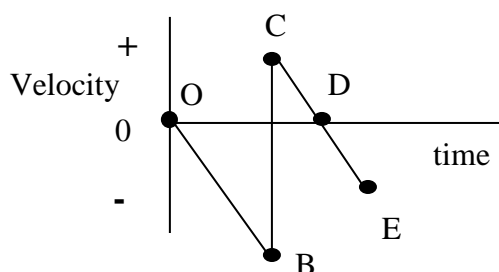
(a) In which direction is the ball travelling during section OB of the graph?

(b) Describe the *velocity* of the ball as represented by section CD of the graph.

(c) Describe the *velocity* of the ball as represented by section DE of the graph.

(d) What happened to the ball at the time represented by point B on the graph?

(e) What happened to the ball at the time represented by point C on the graph?

(f) How does the speed of the ball immediately before rebound from the floor compare with the speed immediately after rebound?

(g) Sketch a graph of acceleration against time for the movement of the ball.¶

9. A ball is thrown vertically upwards and returns to the thrower 3 seconds later. Which velocity-time graph represents the motion of the ball?
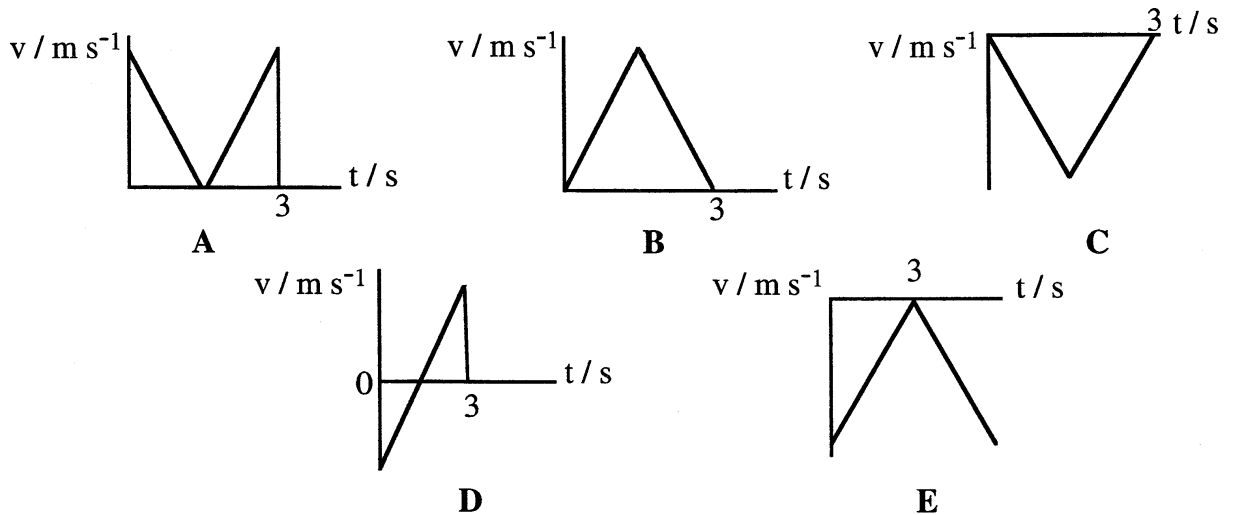
10. A ball is dropped from a height and bounces up and down on a horizontal surface. Which velocity-time graph represents the motion of the ball from the moment it is released?
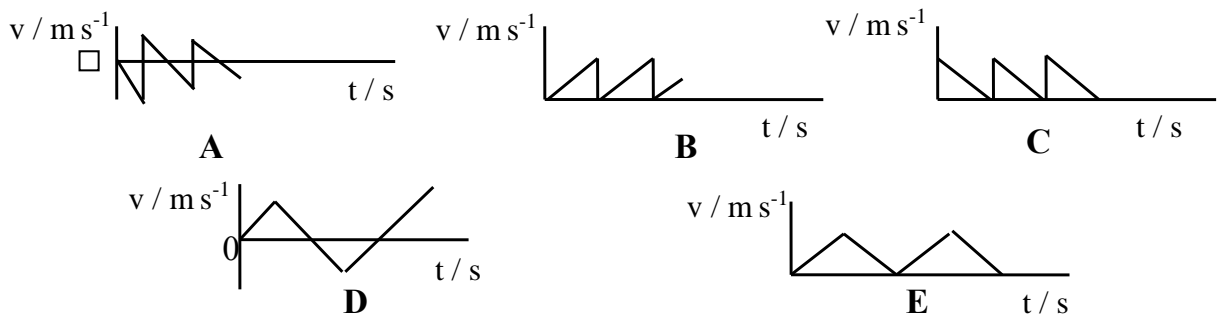
11. Describe how you could measure the acceleration of a trolley that starts from rest and moves down a slope. You are provided with a metre stick and a stopwatch. Your description should include:

   (a)   a diagram
   (b)   a list of the measurements taken
   (c)   how you would use these measurements to calculate the acceleration of the trolley
   (d)   how you would estimate the uncertainties involved in the experiment.

12. Describe a situation where a runner has a displacement of 100 m due north, a velocity of 3 ms^{-1} due north and an acceleration of 2 ms^{-2} due south. Your description should include a diagram.

13. Is it possible for an object to be accelerating but have a constant speed? You must justify your answer.

14. Is it possible for an object to move with a constant *speed* for 5 seconds and have a displacement of 0 m? You must justify your answer.

15 Is it possible for an object to move with a constant *velocity* for 5 s and have a displacement of 0 m? You must justify your answer.

Section 2: Forces, energy and power

Balanced and unbalanced forces

1. State Newton's 1st Law of Motion.

2. A lift of mass 500 kg travels upwards at a constant speed.
   Calculate the tension in the cable that pulls the lift upwards.

3. (a) A fully loaded oil tanker has a mass of $2 \cdot 0 \times 10^8$ kg.
   As the speed of the tanker increases from 0 to a steady maximum speed of 8.0 ms^{-1} the force from the propellers remains constant at 3.0×10^6 N.
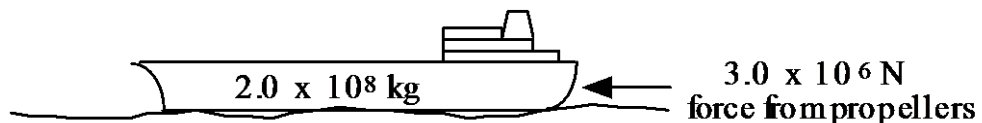
   (i) Calculate the acceleration of the tanker just as it starts from rest.
   (ii) What is the size of the force of friction acting on the tanker when it is travelling at the steady speed of 8.0 ms^{-1}?

   (b) When its engines are stopped, the tanker takes 50 minutes to come to rest from a speed of 8.0 ms^{-1}. Calculate its average deceleration.

4.   The graph shows how the speed of a parachutist varies with time after having jumped from an aeroplane.
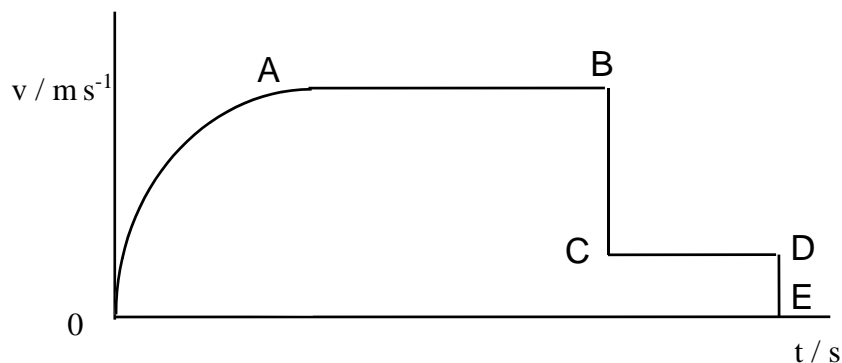
With reference to the origin of the graph and the letters A, B, C, D and E explain the variation of speed with time for each stage of the parachutist's fall.

5.   Two girls push a car of mass 2000 kg. Each applies a force of 50 N and the force of friction is 60 N. Calculate the acceleration of the car.

6.   A boy on a skateboard rides up a slope. The total mass of the boy and the skateboard is 90 kg. He decelerates uniformly from $12 \ ms^{-1}$ to $2 \ ms^{-1}$ in 6 seconds. Calculate the resultant force acting on him.

7.   A box of mass 30 kg is pulled along a rough surface by a constant force of 140 N. The acceleration of the box is $4{\cdot}0 \ ms^{-2}$.

(a)   Calculate the magnitude of the unbalanced force causing the acceleration.
(b)   Calculate the force of friction between the box and the surface.

8.   A car of mass 800 kg is accelerated from rest to $18 \ ms^{-1}$ in 12 seconds.

(a)   What is the size of the resultant force acting on the car?
(b)   How far does the car travel in these 12 seconds?
(c)   At the end of the 12 seconds period the brakes are operated and the car comes to rest in a distance of 50 m.
        What is the size of the average frictional force acting on the car?

9.　(a)　A rocket of mass $4 \cdot 0 \times 10^4$ kg is launched vertically upwards from the surface of the Earth. Its engines produce a constant thrust of $7 \cdot 0 \times 10^5$ N.

　　　　(i)　Draw a diagram showing all the forces acting on the rocket just after take-off.

　　　　(ii)　Calculate the initial acceleration of the rocket.

　　(b)　As the rocket rises the thrust remains constant but the acceleration of the rocket increases. Give three reasons for this increase in acceleration.

　　(c)　Explain in terms of Newton's laws of motion why a rocket can travel from the Earth to the Moon and for most of the journey not burn up any fuel.

10.　A rocket takes off from the surface of the Earth and accelerates to 90 ms^{-1} in a time of $4 \cdot 0$ s. The resultant force acting on it is 40 kN upwards.

　　(a)　Calculate the mass of the rocket.

　　(b)　The average force of friction is 5000 N. Calculate the thrust of the rocket engines.

11.　A helicopter of mass 2000 kg rises upwards with an acceleration of $4 \cdot 00$ m s^{-2}. The force of friction caused by air resistance is 1000 N. Calculate the upwards force produced by the rotors of the helicopter.

12.　A crate of mass 200 kg is placed on a balance, calibrated in newtons, in a lift.

　　(a)　What is the reading on the balance when the lift is stationary?

　　(b)　The lift now accelerates upwards at $1 \cdot 50$ ms^{-2}. What is the new reading on the balance?

　　(c)　The lift then travels upwards at a constant speed of $5 \cdot 00$ m s^{-1}. What is the new reading on the balance?

　　(d)　For the last stage of the journey the lift decelerates at $1 \cdot 50$ m s^{-2} while going up. Calculate the reading on the balance.

13.　A small lift in a hotel is fully loaded and has a total mass of 250 kg. For safety reasons the tension in the pulling cable must never be greater than 3500 N.

　　(a)　What is the tension in the cable when the lift is:

　　　　(i)　at rest

　　　　(ii)　moving upwards at a constant speed of 1 ms^{-1}

       (iii)   moving upwards with a constant acceleration of 2 ms^{-2}

       (iv)   accelerating downwards with a constant acceleration of 2 ms^{-2}.

  (b)   Calculate the maximum permitted upward acceleration of the fully loaded lift.

  (c)   Describe a situation where the lift could have an upward acceleration greater than the value in (b) without breaching safety regulations.

14.   A package of mass 4·00 kg is hung from a spring (Newton) balance attached to the ceiling of a lift.

3 m s^{-2} 4 kg
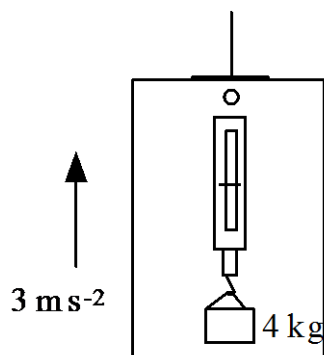
The lift is accelerating upwards at 3·00 ms^{-2}. What is the reading on the spring balance?

15.   The graph shows how the *downward* speed of a lift varies with time.
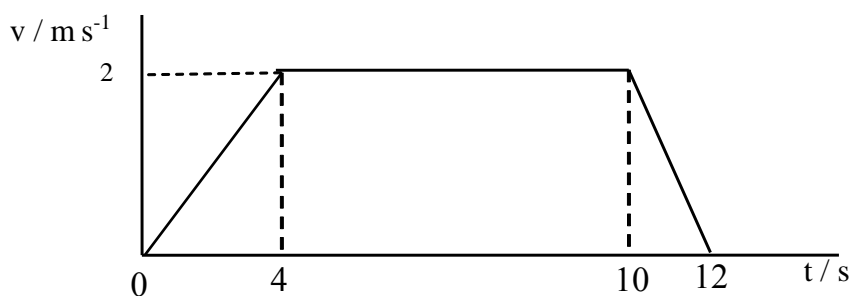
  (a)   Draw the corresponding acceleration against time graph.

  (b)   A 4.0 kg mass is suspended from a spring balance inside the lift. Determine the reading on the balance at each stage of the motion.

16. Two trolleys joined by a string are pulled along a frictionless flat surface as shown.
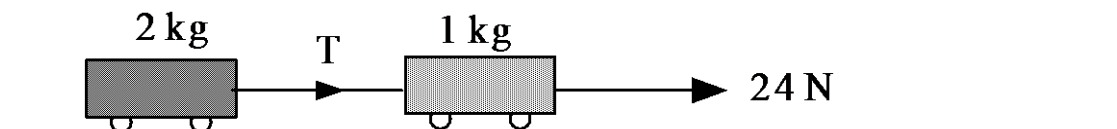
(a) Calculate the acceleration of the trolleys.
(b) Calculate the tension, T, in the string joining the trolleys.

17. A car of mass 1200 kg tows a caravan of mass 1000 kg. The frictional forces on the car and caravan are 200 N and 500 N, respectively. The car accelerates at 2.0 ms^{-2}.

(a) Calculate the force exerted by the engine of the car.
(b) What force does the tow bar exert on the caravan?
(c) The car then travels at a constant speed of 10 ms^{-1}.
Assuming the frictional forces to be unchanged, calculate:
(i) the new engine force
(ii) the force exerted by the tow bar on the caravan.
(d) The car brakes and decelerates at 5·0 ms^{-2}.
Calculate the force exerted by the brakes (assume the other frictional forces remain constant).

18. A log of mass 400 kg is stationary. A tractor of mass 1200 kg pulls the log with a tow rope. The tension in the tow rope is 2000 N and the frictional force on the log is 800 N. How far will the log move in 4 s?

19. A force of 60 N is used to push three blocks as shown.
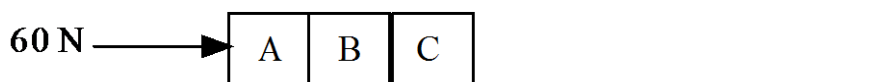
Each block has a mass of 8·0 kg and the force of friction on each block is 4·0 N.

(a) Calculate:
(i) the acceleration of the blocks
(ii) the force that block A exerts on block B
(iii) the force block B exerts on block C.
(b) The pushing force is then reduced until the blocks move at constant speed.
(i) Calculate the value of this pushing force.

       (ii)   Does the force that block A exerts on block B now equal the force that block B exerts on block C? Explain.¶

20.   A 2·0 kg trolley is connected by string to a 1·0 kg mass as shown. The bench and pulley are frictionless.

2 kg

1 kg
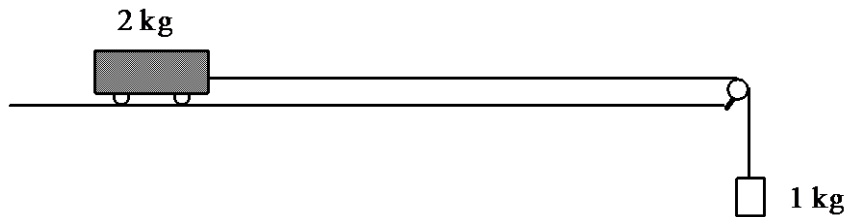
    (a)   Calculate the acceleration of the trolley.
    (b)   Calculate the tension in the string.

Resolution of forces

1.   A man pulls a garden roller with a force of 50 N.¶

50 N

30^0

F_H
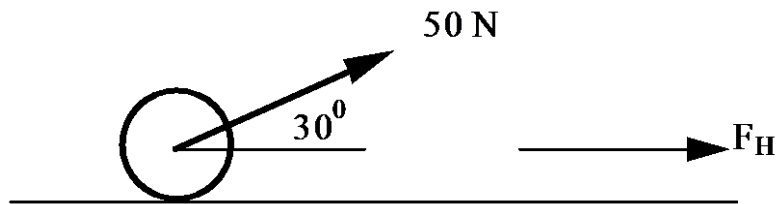
    (a)   Find the effective horizontal force applied to the roller.
    (b)   Describe and explain how the man can increase this effective horizontal force without changing the size of the force applied.

2.   A barge is dragged along a canal as shown below.

500 N

45°

barge
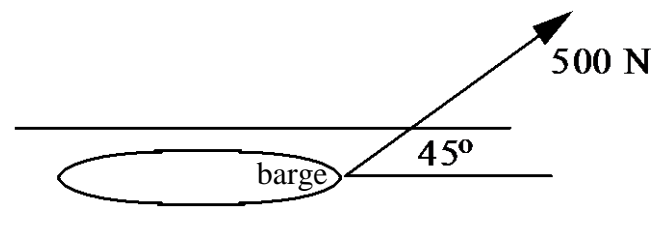
    What is the size of the component of the force parallel to the canal?

3. A toy train of mass 0·20 kg is given a push of 10 N along the rails at an angle of 30º above the horizontal.
    Calculate:

    (a) the magnitude of the component of force along the rails
    (b) the acceleration of the train.

4. A barge of mass 1000 kg is pulled by a rope along a canal as shown.
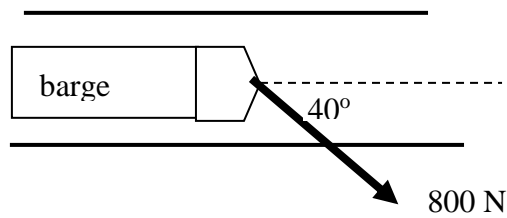
    The rope applies a force of 800 N at an angle of 40º to the direction of the canal. The force of friction between the barge and the water is 100 N. Calculate the acceleration of the barge.

5. A crate of mass 100 kg is pulled along a rough surface by two ropes at the angles shown.
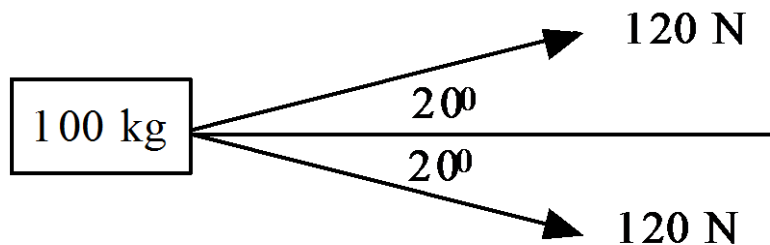
    (a) The crate is moving at a constant speed of $1·0$ ms^{-1}. What is the size of the force of friction?
    (b) The forces are now each increased to 140 N at the same angle. Assuming the friction force remains constant, calculate the acceleration of the crate.

6. A 2·0 kg block of wood is placed on a slope as shown.
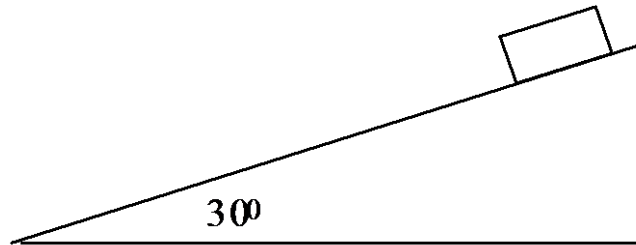
   The block remains stationary. What are the size and direction of the frictional force on the block?

7. A runway is 2·0 m long and raised 0·30 m at one end. A trolley of mass 0·50 kg is placed on the runway. The trolley moves down the runway with constant speed. Calculate the magnitude of the force of friction acting on the trolley.

8. A car of mass 900 kg is parked on a hill. The slope of the hill is 15º to the horizontal. The brakes on the car fail. The car runs down the hill for a distance of 50 m until it crashes into a hedge. The average force of friction on the car as it runs down the hill is 300 N.

   (a) Calculate the component of the weight acting down the slope.
   (b) Find the acceleration of the car.
   (c) Calculate the speed of the car just before it hits the hedge.

9. A trolley of mass 2·0 kg is placed on a slope which makes an angle of 60º to the horizontal.

   (a) A student pushes the trolley and then releases it so that it moves up the slope. The force of friction on the trolley is 1·0 N.
      (i) Why does the trolley continue to move up the slope after it is released?
      (ii) Calculate the unbalanced force on the trolley as it moves up the slope.
      (iii) Calculate the rate at which the trolley loses speed as it moves up the slope.
   (b) The trolley eventually comes to rest then starts to move down the slope.
      (i) Calculate the unbalanced force on the trolley as it moves down the slope.
      (ii) Calculate the acceleration of the trolley down the slope.

Work done, kinetic and potential energy

1. A small ball of mass 0·20 kg is dropped from a height of 4·0 m above the ground. The ball rebounds to a height of 2·0 m.

    (a)   Calculate total loss in energy of the ball.
    (b)   Calculate the speed of the ball just before it hits the ground.
    (c)   Calculate the speed of the ball just after it leaves the ground.

2. A box of mass 70 kg is pulled along a horizontal surface by a horizontal force of 90 N. The box is pulled a distance of 12 m. There is a frictional force of 80 N between the box and the surface.

    (a)   Calculate the total work done by the pulling force.
    (b)   Calculate the amount of kinetic energy gained by the box.

3. A box of mass 2·0 kg is pulled up a frictionless slope as shown.
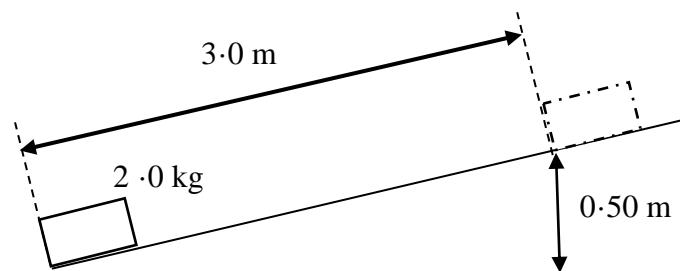
    (a)   Calculate the gravitational potential energy gained by the box when it is pulled up the slope.
    (b)   The block is now released.
          (i)   Use conservation of energy to find the speed of the box at the bottom of the slope.
          (ii)   Use another method to confirm your answer to (i).

4. A winch driven by a motor is used to lift a crate of mass 50 kg through a vertical height of 20 m.

    (a)   Calculate the size of the minimum force required to lift the crate.
    (b)   Calculate the minimum amount of work done by the winch while lifting the crate.
    (c)   The power of the winch is 2·5 kW. Calculate the minimum time taken to lift the crate to the required height.¶

5. A train has a constant speed of 10 m s^{-1} over a distance of $2 \cdot 0$ km. The driving force of the train engine is $3 \cdot 0 \times 10^4$ N.
   What is the power developed by the train engine?

6. An arrow of mass 22 g has a speed of 30 m s^{-1} as it strikes a target. The tip of the arrow goes $3 \cdot 0 \times 10^{-2}$ m into the target.

   (a) Calculate the average force of the target on the arrow.
   (b) What is the time taken for the arrow to come to rest after striking the target, assuming the target exerts a constant force on the arrow?

Section 3: Collisions and explosions

1. What is the momentum of the object in each of the following situations?
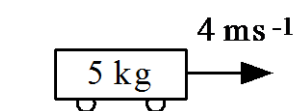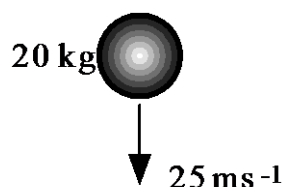
    (a)   (b)   (c)
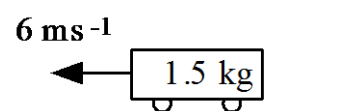
2. A trolley of mass $2 \cdot 0$ kg is travelling with a speed of $1 \cdot 5$ ms^{-1}. The trolley collides and sticks to a stationary trolley of mass $2 \cdot 0$ kg.

    (a)   Calculate the velocity of the trolleys immediately after the collision.
    (b)   Show that the collision is inelastic.

3. A target of mass $4 \cdot 0$ kg hangs from a tree by a long string. An arrow of mass 100 g is fired at the target and embeds itself in the target. The speed of the arrow is 100 ms^{-1} just before it strikes the target. What is the speed of the target immediately after the impact?

4. A trolley of mass $2 \cdot 0$ kg is moving at a constant speed when it collides and sticks to a second stationary trolley. The graph shows how the speed of the $2 \cdot 0$ kg trolley varies with time.
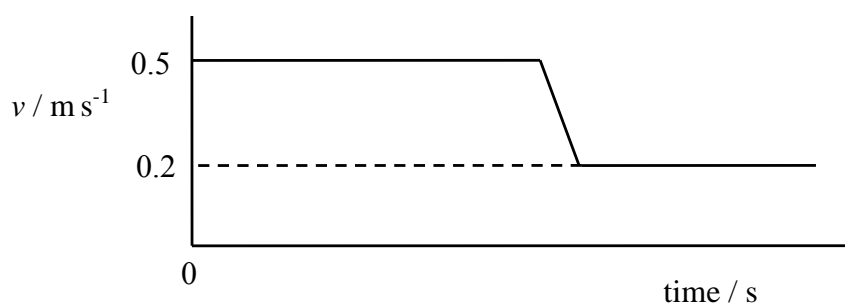
    Determine the mass of the second trolley.

5. In a game of bowls a bowl of mass 1·0 kg is travelling at a speed of 2·0 m s^{-1} when it hits a stationary jack 'straight on'. The jack has a mass of 300 g. The bowl continues to move straight on with a speed of 1·2 ms^{-1} after the collision.

    (a) What is the speed of the jack immediately after the collision?
    (b) How much kinetic energy is lost during the collision?

6. Two space vehicles make a docking manoeuvre (joining together) in space. One vehicle has a mass of 2000 kg and is travelling at 9·0 ms^{-1}. The second vehicle has a mass of 1500 kg and is moving at 8·0 ms^{-1} in the same direction as the first. Determine their common velocity after docking.

7. Two cars are travelling along a race track. The car in front has a mass of 1400 kg and is moving at 20 ms^{-1}. The car behind has a mass of 1000 kg and is moving at 30 ms^{-1}. The cars collide and as a result of the collision the car in front has a speed of 25 ms^{-1}.

    (a) Determine the speed of the rear car after the collision.
    (b) Show clearly whether this collision is elastic or inelastic.

8. One vehicle approaches another from behind as shown.
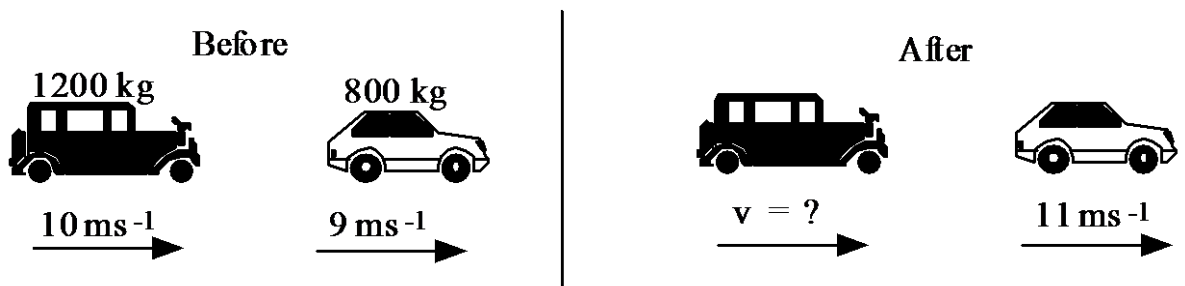
    The vehicle at the rear is moving faster than the one in front and they collide. This causes the vehicle in front to be 'nudged' forward with an increased speed. Determine the speed of the rear vehicle immediately after the collision.

9. A trolley of mass 0·8 kg is travelling at a speed 1·5 ms^{-1}. It collides head-on with another vehicle of mass 1·2 kg travelling at 2·0 ms^{-1} in the opposite direction. The vehicles lock together on impact. Determine the speed and direction of the vehicles after the collision.

10. A firework is launched vertically and when it reaches its maximum height it explodes into two pieces. One piece has a mass of 200 g and moves off with a speed of 10 ms^{-1}. The other piece has a mass of 120 g. What is the velocity of the second piece of the firework?

11. Two trolleys initially at rest and in contact move apart when a plunger on one trolley is released. One trolley with a mass of 2 kg moves off with a speed of 4 ms^{-1}. The other moves off with a speed of 2 m s^{-1}, in the opposite direction. Calculate the mass of this trolley.

12. A man of mass 80 kg and woman of mass 50 kg are skating on ice. At one point they stand next to each other and the woman pushes the man. As a result of the push the man moves off at a speed of 0·5 ms^{-1}. What is the velocity of the woman as a result of the push?

13. Two trolleys initially at rest and in contact fly apart when a plunger on one of them is released. One trolley has a mass of 2·0 kg and moves off at a speed of 2·0 ms^{-1}. The second trolley has a mass of 3·0 kg. Calculate the velocity of this trolley.

14. A cue exerts an average force of 7·00 N on a stationary snooker ball of mass 200 g. The impact of the cue on the ball lasts for 45·0 ms. What is the speed of the ball as it leaves the cue?

15 A football of mass 500 g is stationary. When a girl kicks the ball her foot is in contact with the ball for a time of 50 ms. As a result of the kick the ball moves off at a speed of 10 ms^{-1}. Calculate the average force exerted by her foot on the ball.

16. A stationary golf ball of mass 100 g is struck by a club. The ball moves off at a speed of 30 ms^{-1}. The average force of the club on the ball is 100 N. Calculate the time of contact between the club and the ball.

17. The graph shows how the force exerted by a hockey stick on a stationary hockey ball varies with time.
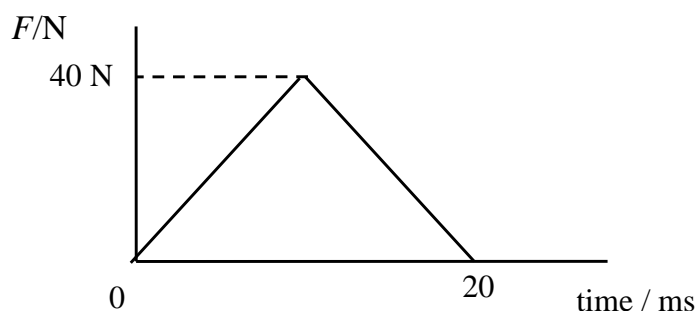
The mass of the ball is 150 g.
Determine the speed of the ball as it leaves the stick.

18. A ball of mass 100 g falls from a height of 0·20 m onto concrete. The ball rebounds to a height of 0·18 m. The duration of the impact is 25 ms. Calculate:

    (a) the change in momentum of the ball caused by the 'bounce'
    (b) the impulse on the ball during the bounce
    (c) the average unbalanced force exerted on the ball by the concrete
    (d) the average unbalanced force of the concrete on the ball.
    (e) What is in the total average upwards force on the ball during impact?

19. A rubber ball of mass 40·0 g is dropped from a height of 0·800 m onto the pavement. The ball rebounds to a height of 0·450 m. The average force of contact between the pavement and the ball is 2·80 N.

    (a) Calculate the velocity of the ball just before it hits the ground and the velocity just after hitting the ground.
    (b) Calculate the time of contact between the ball and pavement.

20. A ball of mass 400 g travels falls from rest and hits the ground. The velocity-time graph represents the motion of the ball for the first 1·2 s after it starts to fall.
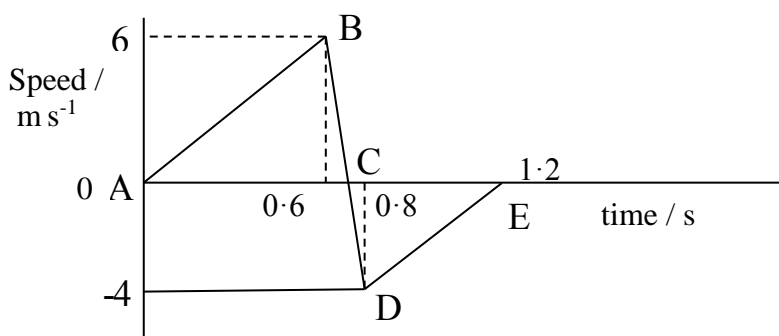
    (a) Describe the motion of the ball during sections AB, BC, CD and DE on the graph.
    (b) What is the time of contact of the ball with the ground?
    (c) Calculate the average unbalanced force of the ground on the ball.
    (d) How much energy is lost due to contact with the ground?

21. Water with a speed of 50 ms^{-1} is ejected horizontally from a fire hose at a rate of 25 kg s^{-1}. The water hits a wall horizontally and does not rebound from the wall. Calculate the average force exerted on the wall by the water.

22. A rocket ejects gas at a rate of 50 kg s^{-1}, ejecting it with a constant speed of 1800 ms^{-1}. Calculate magnitude of the force exerted by the ejected gas on the rocket.

23. Describe in detail an experiment that you would do to determine the average force between a football boot and a football as the ball is being kicked. Draw a diagram of the apparatus and include all the measurements taken and details of the calculations carried out.

24. A 2·0 kg trolley travelling at 6·0 ms^{-1} collides with a stationary 1·0 kg trolley. The trolleys remain connected after the collision.

    (a) Calculate:
        (i)   the velocity of the trolleys just after the collision
        (ii) the momentum gained by the 1·0 kg trolley
        (iii) the momentum lost by the 2·0 kg trolley.

    (b) The collision lasts for 0·50 s. Calculate the magnitude of the average force acting on each trolley.

25. In a problem two objects, having known masses and velocities, collide and stick together. Why does the problem ask for the velocity *immediately* after collision to be calculated?

26. A Newton's cradle apparatus is used to demonstrate conservation of momentum.
    Four steel spheres, each of mass 0.1 kg, are suspended so that they are in a straight line.
    Sphere 1 is pulled to the side and released, as shown in diagram I.
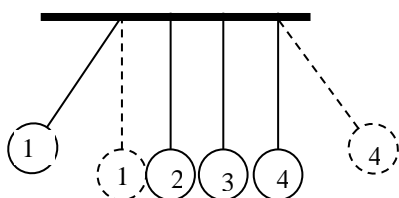
Diagram I
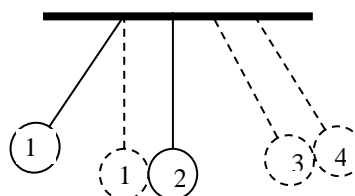
Diagram II

When sphere 1 strikes sphere 2 (as shown by the dotted lines) then sphere 4 moves off the line and reaches the position shown by the dotted lines.

The student estimates that sphere 1 has a speed of 2 ms^{-1} when it strikes sphere 2. She also estimates that sphere 4 leaves the line with an initial speed of 2 ms^{-1}. Hence conservation of momentum has been demonstrated.

A second student suggests that when the demonstration is repeated there is a possibility that spheres 3 and 4, each with a speed of 0·5 ms^{-1}, could move off the line as shown in diagram II.

Use your knowledge of physics to show this is not possible.

Section 4: Gravitation

Projectiles

1. A plane is travelling with a horizontal velocity of 350 ms^{-1} at a height
    of 300 m. A box is dropped from the plane.
    The effects of friction can be ignored.

    (a) Calculate the time taken for the box to reach the ground.
    (b) Calculate the *horizontal* distance between the point where the box
         is dropped and the point where it hits the ground.
    (c) What is the position of the plane relative to the box when the box
         hits the ground?

2. A projectile is fired horizontally with a speed of 12·0 ms^{-1} from the
    edge of a cliff. The projectile hits the sea at a point 60·0 m from the
    base of the cliff.

    (a) Calculate the time of flight of the projectile.
    (b) What is the height of the starting point of the projectile above sea
         level?
         State any assumptions you have made.

3. A ball is thrown horizontally with a speed of 15 ms^{-1} from the top of a
    vertical cliff. It reaches the horizontal ground at a distance of 45 m
    from the foot of the cliff.

    (a) (i)   Draw a graph of vertical speed against time for the ball for
              the time from when it is thrown until it hits the ground.
         (ii) Draw a graph of horizontal speed against time for the ball.
    (b) Calculate the *velocity* of the ball 2 s after it is thrown.
         (Magnitude and direction are required.)

4. A football is kicked up at an angle of 70º above the horizontal at
    15 ms^{-1}. Calculate:

    (a) the horizontal component of the velocity
    (b) the vertical component of the velocity.

5. A projectile is fired across level ground and takes 6 s to travel from A to B.
    The highest point reached is C. Air resistance is negligible.
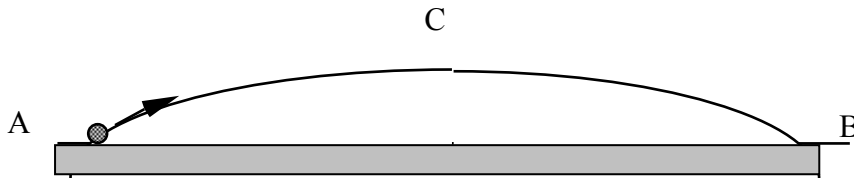
Velocity-time graphs for the flight are shown below. V_H is the horizontal velocity and V_V is the vertical velocity.
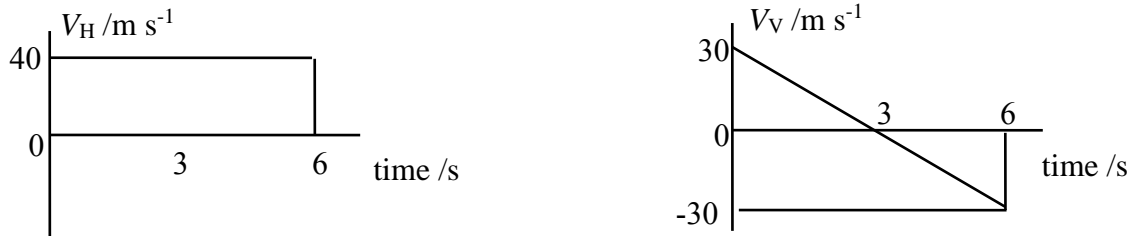
(a) Describe:
   (i)   the horizontal motion of the projectile
   (ii) the vertical motion of the projectile.
(b) Use a vector diagram to find the speed and angle at which the projectile was fired from point A.
(c) Find the speed at position C. Explain why this is the smallest speed of the projectile.
(d) Calculate the height above the ground of point C.
(e) Find the horizontal range of the projectile.

6. A ball of mass 5·0 kg is thrown with a velocity of 40 ms^{-1} at an angle of 30° to the horizontal.
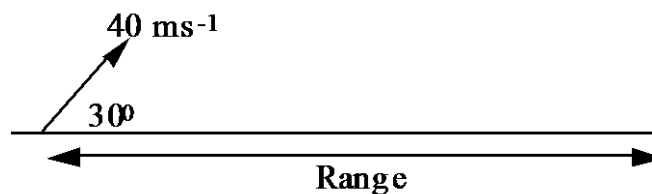
Calculate:

(a) the vertical component of the initial velocity of the ball
(b) the maximum vertical height reached by the ball

(c)   the time of flight for the whole trajectory

(d)   the horizontal range of the ball.

7.   A launcher is used to fire a ball with a velocity of 100 ms^{-1} at an angle of 60° to the ground. The ball strikes a target on a hill as shown.
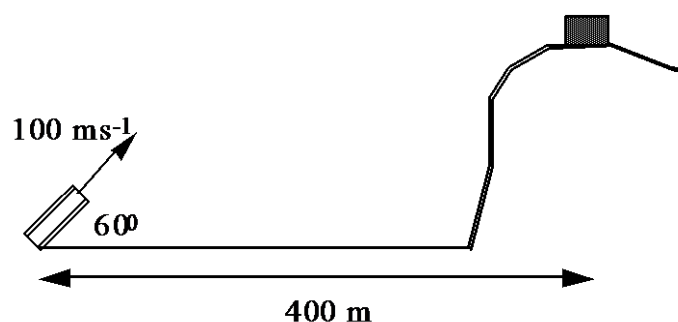
(a)   Calculate the time taken for the ball to reach the target.

(b)   What is the height of the target above the launcher?

8.   A stunt driver attempts to jump across a canal of width 10 m.
The vertical drop to the other side is 2 m as shown.
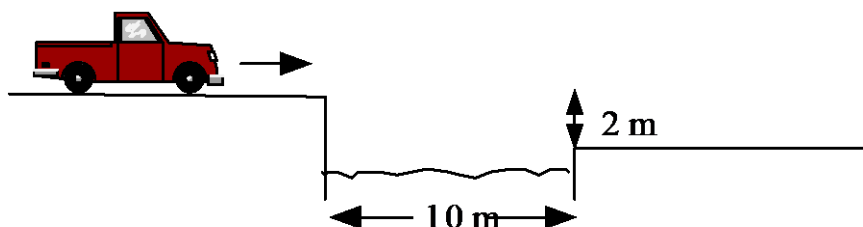
(a)   Calculate the minimum horizontal speed required so that the car reaches the other side.

(b)   Explain why your answer to (a) is the minimum horizontal speed required.

(c)   State any assumptions you have made.

9.   A ball is thrown horizontally from a cliff. The effect of friction can be ignored.

(a)   Is there any time when the velocity of the ball is parallel to its acceleration? Justify your answer.

(b)   Is there any time when the velocity of the ball is perpendicular to its acceleration? Justify your answer.

10. A ball is thrown at an angle of 45° to the horizontal. The effect of friction can be ignored.

    (a) Is there any time when the velocity of the ball is parallel to its acceleration? Justify your answer.
    (b) Is there any time when the velocity of the ball is perpendicular to its acceleration? Justify your answer.

11. A small ball of mass 0·3 kg is projected at an angle of 60° to the horizontal. The initial speed of the ball is 20 ms^{-1}.

    20 m s^{-1}

    60°
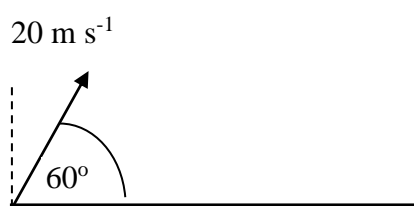
    Show that the maximum gain in potential energy of the ball is 45 J.

12. A ball is thrown horizontally with a speed of 20 ms^{-1} from a cliff. The effects of air resistance can be ignored. How long after being thrown will the velocity of the ball be at an angle of 45° to the horizontal?

Gravity and mass

In the following questions, when required, use the following data:

Gravitational constant = $6·67 \times 10^{-11}$ N m^2 kg^{-2}

1. State the inverse square law of gravitation.

2. Show that the force of attraction between two large ships, each of mass $5·00 \times 10^7$ kg and separated by a distance of 20 m, is 417 N.

3. Calculate the gravitational force between two cars parked 0·50 m apart. The mass of each car is 1000 kg.

4. In a hydrogen atom an electron orbits a proton with a radius of $5·30 \times 10^{-11}$ m. The mass of an electron is $9·11 \times 10^{-31}$ kg and the mass of a proton is $1·67 \times 10^{-27}$ kg. Calculate the gravitational force of attraction between the proton and the electron in a hydrogen atom.

5. The distance between the Earth and the Sun is $1 \cdot 50 \times 10^{11}$ m. The mass of the Earth is $5 \cdot 98 \times 10^{24}$ kg and the mass of the Sun is $1 \cdot 99 \times 10^{30}$ kg. Calculate the gravitational force between the Earth and the Sun.

6. Two protons exert a gravitational force of $1 \cdot 16 \times 10^{-35}$ N on each other. The mass of a proton is $1 \cdot 67 \times 10^{-27}$ kg. Calculate the distance separating the protons.

Section 5: Special relativity

Relativity – Fundamental principles

1. A river flows at a constant speed of 0.5 ms^{-1} south. A canoeist is able to row at a constant speed of 1.5 ms^{-1}.

    (a) Determine the velocity of the canoeist relative to the river bank when the canoeist is moving upstream.
    (b) Determine the velocity of the canoeist relative to the river bank when the canoeist is moving downstream.

2. In an airport, passengers use a moving walkway. The moving walkway is travelling at a constant speed of 0.8 ms^{-1} and is travelling east. For the following people, determine the velocity of the person relative to the ground:

    (a) a woman standing at rest on the walkway
    (b) a man walking at 2.0 ms^{-1} in the same direction as the walkway is moving
    (c) a boy running west at 3.0 ms^{-1}.

3. The steps of an escalator move at a steady speed of 1.0 ms^{-1} relative to the stationary side of the escalator.

    (a) A man walks up the steps of the escalator at 2.0 ms^{-1}. Determine the speed of the man relative to the side of the escalator.
    (b) A boy runs down the steps of the escalator at 3.0 ms^{-1}. Determine the speed of the boy relative to the side of the escalator.

4. In the following sentences the words represented by the letters A, B, C, D, E, F and G are missing:

    In _____**A**_____ Theory of Special Relativity the laws of physics are the

    _____**B**_____ for all observers, at rest or moving at constant velocity

    with respect to each other ie _____**C**_____ acceleration.

An observer, at rest or moving at constant _____**D**____ has their own frame of reference.

In all frames of reference the _____**E**____, c, remains the same regardless of whether the source or observer is in motion.

Einstein's principles that the laws of physics and the speed of light are the same for all observers leads to the conclusion that moving clocks run _____**F**____ (time dilation) and moving objects are _____**G**____ (length contraction).

Match each letter with the correct word from the list below:

acceleration	different	Einstein's	fast
lengthened	Newton's	same	shortened
slow	speed of light	velocity	zero

5.   An observer at rest on the Earth sees an aeroplane fly overhead at a constant speed of 2000 $km\,h^{-1}$. At what speed, in $km\,h^{-1}$, does the pilot of the aeroplane see the Earth moving?

6.   A scientist is in a windowless lift. Can the scientist determine whether the lift is moving with a:

(a)   uniform velocity
(b)   uniform acceleration?

7.   Spaceship A is moving at a speed of $2\cdot4 \times 10^8$ ms^{-1}. It sends out a light beam in the forwards direction. Meanwhile another spaceship B is moving towards spaceship A at a speed of $2\cdot4 \times 10^8$ ms^{-1}. At what speed does spaceship B see the light beam from spaceship A pass?

8.   A spacecraft is travelling at a constant speed of $7\cdot5 \times 10^7$ ms^{-1}. It emits a pulse of light when it is $3\cdot0 \times 10^{10}$ m from the Earth as measured by an observer on the Earth.
Calculate the time taken for the pulse of light to reach the Earth according to a clock on the Earth when the spacecraft is moving:

(a)   away from the Earth
(b)   towards the Earth.

9. A spaceship is travelling away from the Earth at a constant speed of $1·5 \times 10^8$ ms^{-1}. A light pulse is emitted by a lamp on the Earth and travels towards the spaceship. Find the speed of the light pulse according to an observer on:

    (a) the Earth
    (b) the spaceship.

10. Convert the following fraction of the speed of light into a value in ms^{-1}:

    (a) 0·1 c
    (b) 0·5 c
    (c) 0·6 c
    (d) 0·8 c

11. Convert the following speeds into a fraction of the speed of light:

    (a) $3·0 \times 10^8$ ms^{-1}
    (b) $2·0 \times 10^8$ ms^{-1}
    (c) $1·5 \times 10^8$ ms^{-1}
    (d) $1·0 \times 10^8$ ms^{-1}

Relativity – Time dilation

1. Write down the relationship involving the proper time t and dilated time t' between two events which are observed in two different frames of reference moving at a speed, v, relative to one another (where the proper time is the time measured by an observer at rest with respect to the two events and the dilated time is the time measured by another observer moving at a speed, v, relative to the two events).

2. In the table shown, use the relativity equation for time dilation to calculate the value of each missing quantity (a) to (f) for an object moving at a constant speed relative to the Earth.

Dilated time	Proper time	Speed of object / ms^{-1}
(a)	20 h	$1·00 \times 10^8$
(b)	10 year	$2·25 \times 10^8$
1400 s	(c)	$2·00 \times 10^8$
1.40×10^{-4} s	(d)	$1·00 \times 10^8$
84 s	60 s	(e)
21 minutes	20 minutes	(f)

3.   Two observers P and Q synchronise their watches at 11.00 am just as observer Q passes the Earth at a speed of 2×10^8 ms^{-1}.

   (a)   At 11.15 am according to observer P's watch, observer P looks at Q's watch through a telescope. Calculate the time, to the nearest minute, that observer P sees on Q's watch.
   (b)   At 11.15 am according to observer Q's watch, observer Q looks at P's watch through a telescope. Calculate the time, to the nearest minute, that observer Q sees on P's watch.

4.   The lifetime of a star is 10 billion years as measured by an observer at rest with respect to the star. The star is moving away from the Earth at a speed of 0·81 c.
   Calculate the lifetime of the star according to an observer on the Earth.

5.   A spacecraft moving with a constant speed of 0·75 c passes the Earth. An astronaut on the spacecraft measures the time taken for Usain Bolt to run 100 m in the sprint final at the 2008 Olympic Games. The astronaut measures this time to be 14·65 s. Calculate Usain Bolt's winning time as measured on the Earth.

6.   A scientist in the laboratory measures the time taken for a nuclear reaction to occur in an atom. When the atom is travelling at $8·0 \times 10^7$ ms^{-1} the reaction takes $4·0 \times 10^{-4}$ s. Calculate the time for the reaction to occur when the atom is at rest.

7.   The light beam from a lighthouse sweeps its beam of light around in a circle once every 10 s. To an astronaut on a spacecraft moving towards the Earth, the beam of light completes one complete circle every 14 s. Calculate the speed of the spacecraft relative to the Earth.

8.   A rocket passes two beacons that are at rest relative to the Earth. An astronaut in the rocket measures the time taken for the rocket to travel from the first beacon to the second beacon to be 10·0 s. An observer on Earth measures the time taken for the rocket to travel from the first beacon to the second beacon to be 40·0 s. Calculate the speed of the rocket relative to the Earth.

9.   A spacecraft travels to a distant planet at a constant speed relative to the Earth. A clock on the spacecraft records a time of 1 year for the journey while an observer on Earth measures a time of 2 years for the journey. Calculate the speed, in ms^{-1}, of the spacecraft relative to the Earth.

Relativity – Length contraction

1. Write down the relationship involving the proper length *l* and contracted length *l'* of a moving object observed in two different frames of reference moving at a speed, *v*, relative to one another (where the proper length is the length measured by an observer at rest with respect to the object and the contracted length is the length measured by another observer moving at a speed, *v*, relative to the object).

2. In the table shown, use the relativity equation for length contraction to calculate the value of each missing quantity (a) to (f) for an object moving at a constant speed relative to the Earth.

Contracted length	*Proper length*	*Speed of object* / ms^{-1}
(a)	5·00 m	$1·00 \times 10^8$
(b)	15.0 m	$2·00 \times 10^8$
0·15 km	(c)	$2·25 \times 10^8$
150 mm	(d)	$1·04 \times 10^8$
30 m	35 m	(e)
10 m	11 m	(f)

3. A rocket has a length of 20 m when at rest on the Earth. An observer, at rest on the Earth, watches the rocket as it passes at a constant speed of $1·8 \times 10^8$ ms^{-1}. Calculate the length of the rocket as measured by the observer.

4. A pi meson is moving at 0·90 c relative to a magnet. The magnet has a length of 2·00 m when at rest to the Earth. Calculate the length of the magnet in the reference frame of the pi meson.

5. In the year 2050 a spacecraft flies over a base station on the Earth. The spacecraft has a speed of 0·8 c. The length of the moving spacecraft is measured as 160 m by a person on the Earth. The spacecraft later lands and the same person measures the length of the now stationary spacecraft. Calculate the length of the stationary spacecraft.

6. A rocket is travelling at 0·50 c relative to a space station. Astronauts on the rocket measure the length of the space station to be 0.80 km. Calculate the length of the space station according to a technician on the space station.

7. A metre stick has a length of 1·00 m when at rest on the Earth. When in motion relative to an observer on the Earth the same metre stick has a length of 0·50 m. Calculate the speed, in ms^{-1}, of the metre stick.

8.   A spaceship has a length of 220 m when measured at rest on the Earth.
      The spaceship moves away from the Earth at a constant speed and an
      observer, on the Earth, now measures its length to be 150 m.
      Calculate the speed of the spaceship in ms^{-1}.

9.   The length of a rocket is measured when at rest and also when moving
      at a constant speed by an observer at rest relative to the rocket. The
      observed length is 99·0 % of its length when at rest. Calculate the speed
      of the rocket.

Relativity questions

1.   Two points A and B are separated by 240 m as measured by metre
      sticks at rest on the Earth. A rocket passes along the line connecting A
      and B at a constant speed. The time taken for the rocket to travel from
      A to B, as measured by an observer on the Earth, is $1·00 \times 10^{-6}$ s.

      (a)   Show that the speed of the rocket relative to the Earth is
             $2·40 \times 10^{8}$ ms^{-1}.
      (b)   Calculate the time taken, as measured by a clock in the rocket, for
             the rocket to travel from A to B.
      (c)   What is the distance between points A and B as measured by
             metre sticks carried by an observer travelling in the rocket?

2.   A spacecraft is travelling at a constant speed of 0·95 c. The spacecraft
      travels at this speed for 1 year, as measured by a clock on the Earth.

      (a)   Calculate the time elapsed, in years, as measured by a clock in the
             spacecraft.
      (b)   Show that the distance travelled by the spacecraft as measured by
             an observer on the spacecraft is $2·8 \times 10^{15}$ m.
      (c)   Calculate the distance, in m, the spacecraft will have travelled as
             measured by an observer on the Earth.

3.   A pi meson has a mean lifetime of $2·6 \times 10^{-8}$ s when at rest. A pi meson
      moves with a speed of 0·99 c towards the surface of the Earth.

      (a)   Calculate the mean lifetime of this pi meson as measured by an
             observer on the Earth.
      (b)   Calculate the mean distance travelled by the pi meson as
             measured by the observer on the Earth.

4. A spacecraft moving at $2 \cdot 4 \times 10^8$ ms^{-1} passes the Earth. An astronaut on the spacecraft finds that it takes $5 \cdot 0 \times 10^{-7}$ s for the spacecraft to pass a small marker which is at rest on the Earth.

    (a) Calculate the length, in m, of the spacecraft as measured by the astronaut.
    (b) Calculate the length of the spacecraft as measured by an observer at rest on the Earth.

5. A neon sign flashes with a frequency of $0 \cdot 2$ Hz.

    (a) Calculate the time between flashes.
    (b) An astronaut on a spacecraft passes the Earth at a speed of $0 \cdot 84$ c and sees the neon light flashing. Calculate the time between flashes as observed by the astronaut on the spacecraft.

6. When at rest, a subatomic particle has a lifetime of $0 \cdot 15$ ns. When in motion relative to the Earth the particle's lifetime is measured by an observer on the Earth as $0 \cdot 25$ ns. Calculate the speed of the particle.

7. A meson is $10 \cdot 0$ km above the Earth's surface and is moving towards the Earth at a speed of $0 \cdot 999$ c.

    (a) Calculate the distance, according to the meson, travelled before it strikes the Earth.
    (b) Calculate the time taken, according to the meson, for it to travel to the surface of the Earth.

8. The star Alpha Centauri is $4 \cdot 2$ light years away from the Earth. A spacecraft is sent from the Earth to Alpha Centauri. The distance travelled, as measured by the spacecraft, is $3 \cdot 6$ light years.

    (a) Calculate the speed of the spacecraft relative to the Earth.
    (b) Calculate the time taken, in seconds, for the spacecraft to reach Alpha Centauri as measured by an observer on the Earth.
    (c) Calculate the time taken, in seconds, for the spacecraft to reach Alpha Centauri as measured by a clock on the spacecraft.

9. Muons, when at rest, have a mean lifetime of $2 \cdot 60 \times 10^{-8}$ s. Muons are produced 10 km above the Earth. They move with a speed of $0 \cdot 995$ c towards the surface of the Earth.

    (a) Calculate the mean lifetime of the moving muons as measured by an observer on the Earth.
    (b) Calculate the mean distance travelled by the muons as measured by an observer on the Earth.
    (c) Calculate the mean distance travelled by the muons as measured by the muons.

Section 6: The expanding universe

The Doppler effect and redshift of galaxies

In the following questions, when required, use the approximation for speed of sound in air = 340 ms^{-1}.

1. In the following sentences the words represented by the letters A, B, C and D are missing:

    A moving source emits a sound with frequency f_s. When the source is moving towards a stationary observer, the observer hears a ____**A**_____ frequency f_o. When the source is moving away from a stationary observer, the observer hears a ____**B**_____ frequency f_o. This is known as the _____**C**____ ____**D**_____.

    Match each letter with the correct word from the list below:

    Doppler   effect   higher   louder   lower
    quieter   softer

2. Write down the expression for the observed frequency f_o, detected when a source of sound waves in air of frequency f_s moves:

    (a)   towards a stationary observer at a constant speed, v_s
    (b)   away from a stationary observer at a constant speed, v_s.

3. In the table shown, calculate the value of each missing quantity (a) to
    (f), for a source of sound moving in air relative to a stationary observer.

Frequency heard by stationary observer / Hz	Frequency of source / Hz	Speed of source moving towards observer / ms^{-1}	Speed of source moving away from observer / ms^{-1}
(a)	400	10	–
(b)	400	–	10
850	(c)	20	–
1020	(d)	–	5
2125	2000	(e)	–
170	200	–	(f)

4. A girl tries out an experiment to illustrate the Doppler effect by
    spinning a battery-operated siren around her head. The siren emits
    sound waves with a frequency of 1200 Hz.
    Describe what would be heard by a stationary observer standing a few
    metres away.

5. A police car emits sound waves with a frequency of 1000 Hz from its
    siren. The car is travelling at 20 ms^{-1}.

    (a) Calculate the frequency heard by a stationary observer as the
        police car moves towards her.
    (b) Calculate the frequency heard by the same observer as the police
        car moves away from her.

6. A student is standing on a station platform. A train approaching the
    station sounds its horn as it passes through the station. The train is
    travelling at a speed of 25 ms^{-1}. The horn has a frequency of 200 Hz.

    (a) Calculate the frequency heard as the train is approaching the
        student.
    (b) Calculate the frequency heard as the train is moving away from
        the student.

7. A man standing at the side of the road hears the horn of an approaching
    car. He hears a frequency of 470 Hz. The horn on the car has a
    frequency of 450 Hz.
    Calculate the speed of the car.

8. A source of sound emits waves of frequency 500 Hz. This is detected as 540 Hz by a stationary observer as the source of sound approaches. Calculate the frequency of the sound detected as the source moves away from the stationary observer.

9. A whistle of frequency 540 vibrations per second rotates in a circle of radius 0·75 m with a speed of 10 ms^{-1}. Calculate the lowest and highest frequency heard by a listener some distance away at rest with respect to the centre of the circle.

10. A woman is standing at the side of a road. A lorry, moving at 20 ms^{-1}, sounds its horn as it is passing her. The lorry is moving at 20 ms^{-1} and the horn has a frequency of 300 Hz.

    (a) Calculate the wavelength heard by the woman when the lorry is approaching her.
    (b) Calculate the wavelength heard by the woman when the lorry is moving away from her.

11. A siren emitting a sound of frequency 1000 vibrations per second moves away from you towards the base of a vertical cliff at a speed of 10 ms^{-1}.

    (a) Calculate the frequency of the sound you hear coming directly from the siren.
    (b) Calculate the frequency of the sound you hear reflected from the cliff.

12. A sound source moves away from a stationary listener. The listener hears a frequency that is 10% lower than the source frequency. Calculate the speed of the source.

13. A bat flies towards a tree at a speed of 3·60 ms^{-1} while emitting sound of frequency 350 kHz. A moth is resting on the tree directly in front of the bat.

    (a) Calculate the frequency of sound heard by the bat.
    (b) The bat decreases its speed towards the tree. Does the frequency of sound heard by the moth increase, decrease or stays the same? Justify your answer.
    (c) The bat now flies directly away from the tree with a speed of 4·50 ms^{-1} while emitting the same frequency of sound. Calculate the new frequency of sound heard by the moth.

14. The siren on a police car has a frequency of 1500 Hz. The police car is moving at a constant speed of 54 $km\,h^{-1}$.

    (a)   Show that the police car is moving at 15 ms^{-1}.
    (b)   Calculate the frequency heard when the car is moving towards a stationary observer.
    (c)   Calculate the frequency heard when the car is moving away from a stationary observer.

15. A source of sound emits a signal at 600 Hz. This is observed as 640 Hz by a stationary observer as the source approaches.
    Calculate the speed of the moving source.

16. A battery-operated siren emits a constant note of 2200 Hz. It is rotated in a circle of radius 0·8 m at 3·0 revolutions per second. A stationary observer, standing some distance away, listens to the note made by the siren.

    (a)   Show that the siren has a constant speed of 15·1 ms^{-1}.
    (b)   Calculate the minimum frequency heard by the observer.
    (c)   Calculate the maximum frequency heard by the observer.

17. You are standing at the side of the road. An ambulance approaches you with its siren on. As the ambulance approaches, you hear a frequency of 460 Hz and as the ambulance moves away from you, a frequency of 410 Hz. The nearest hospital is 3 km from where you are standing. Estimate the time for the ambulance to reach the hospital. Assume that the ambulance maintains a constant speed during its journey to the hospital.

18. On the planet Lts, a nattra moves towards a stationary ndo at 10 ms^{-1}. The nattra emits sound waves of frequency 1100 Hz. The stationary ndo hears a frequency of 1200 Hz.
    Calculate the speed of sound on the planet Lts.

19. In the following sentences the words represented by the letters A, B, C, D and E are missing:

    A hydrogen source of light gives out a number of emission lines. The wavelength of one of these lines is measured. When the light source is on the Earth, and at rest, the value of this wavelength is λ_{rest}. When the same hydrogen emission line is observed, on the Earth, in light coming from a distant star the value of the wavelength is $\lambda_{observed}$.

When a star is moving away from the Earth $\lambda_{observed}$ is ____A_____ than λ_{rest}. This is known as the ____B_____ shift.

When the distant star is moving towards the Earth $\lambda_{observed}$ is ____C_____ than λ_{rest}. This is known as the ____D_____ shift.

Measurements on many stars indicate that most stars are moving ____E_____ from the Earth.

Match each letter with the correct word from the list below:

away   blue   longer   red   shorter   towards.

20.   In the table shown, calculate the value of each missing quantity.

Fractional change in wavelength, z	Wavelength of light on Earth λ_{rest} / nm	Wavelength of light observed from star, $\lambda_{observed}$ / nm
(a)	365	402
(b)	434	456
$8 \cdot 00 \times 10^{-2}$	486	(c)
$4 \cdot 00 \times 10^{-2}$	656	(d)
$5 \cdot 00 \times 10^{-2}$	(e)	456
$1 \cdot 00 \times 10^{-1}$	(f)	402

Hubble's law

In the following questions, when required, use the approximation for
$H_o = 2 \cdot 4 \times 10^{-18}$ s^{-1}

1.   Convert the following distances in light years into distances in metres.

   (a)   1 light year
   (b)   50 light years
   (c)   100, 000 light years
   (d)   16, 000, 000, 000 light years

2.   Convert the following distances in metres into distances in light years.

   (a)   Approximate distance from the Earth to our Sun = $1 \cdot 44 \times 10^{11}$ m.
   (b)   Approximate distance from the Earth to next nearest star Alpha Centauri = 3.97×10^{16} m.

(c)   Approximate distance from the Earth to a galaxy in the constellation of Virgo = $4\cdot91 \times 10^{23}$ m.

3.   In the table shown, calculate the value of each missing quantity.

Speed of galaxy relative to Earth / ms^{-1}	Approximate distance from Earth to galaxy / m	Fractional change in wavelength, z
(a)	7.10×10^{22}	(b)
(c)	1.89×10^{24}	(d)
$1\cdot70 \times 10^6$	(e)	(f)
$2\cdot21 \times 10^6$	(g)	(h)

4.   Light from a distant galaxy is found to contain the spectral lines of hydrogen. The light causing one of these lines has a measured wavelength of 466 nm. When the same line is observed from a hydrogen source on Earth it has a wavelength of 434 nm.

(a)   Calculate the Doppler shift, z, for this galaxy.
(b)   Calculate the speed at which the galaxy is moving relative to the Earth.
(c)   In which direction, towards or away from the Earth, is the galaxy moving?

5.   Light of wavelength 505 nm forms a line in the spectrum of an element on Earth. The same spectrum from light from a galaxy in Ursa Major shows this line shifted to correspond to light of wavelength 530 nm.

(a)   Calculate the speed that the galaxy is moving relative to the Earth.
(b)   Calculate the approximate distance, in metres, the galaxy is from the Earth.

6.   A galaxy is moving away from the Earth at a speed of $0\cdot074$ c.

(a)   Convert $0\cdot074$ c into a speed in m s^{-1}.
(b)   Calculate the approximate distance, in metres, of the galaxy from the Earth.

7.   A distant star is travelling directly away from the Earth at a speed of $2\cdot4 \times 10^7$ ms^{-1}.

(a)   Calculate the value of z for this star.

(b) A hydrogen line in the spectrum of light from this star is measured to be 443 nm. Calculate the wavelength of this line when it observed from a hydrogen source on the Earth.

8. A line in the spectrum from a hydrogen atom has a wavelength of 489 nm on the Earth. The same line is observed in the spectrum of a distant star but with a longer wavelength of 538 nm.

   (a) Calculate the speed, in ms^{-1}, at which the star is moving away from the Earth.
   (b) Calculate the approximate distance, in metres and in light years, of the star from the Earth.

9. The galaxy Corona Borealis is approximately 1 000 million light years away from the Earth. Calculate the speed at which Corona Borealis is moving away from the Earth.

10. A galaxy is moving away from the Earth at a speed of $3 \cdot 0 \times 10^7 \ ms^{-1}$. The frequency of an emission line coming from the galaxy is measured. The light forming the same emission line, from a source on Earth, is observed to have a frequency of $5 \cdot 00 \times 10^{14}$ Hz.

    (a) Show that the wavelength of the light corresponding to the emission line from the source on the Earth is $6 \cdot 00 \times 10^{-7}$ m.
    (b) Calculate the frequency of the light forming the emission line coming from the galaxy.

11. A distant quasar is moving away from the Earth. Hydrogen lines are observed coming from this quasar. One of these lines is measured to be 20 nm longer than the same line, of wavelength 486 nm from a source on Earth.

    (a) Calculate the speed at which the quasar is moving away from the Earth.
    (b) Calculate the approximate distance, in millions of light years, that the quasar is from the Earth.

12. A hydrogen source, when viewed on the Earth, emits a red emission line of wavelength 656 nm. Observations, for the same line in the spectrum of light from a distant star, give a wavelength of 660 nm. Calculate the speed of the star relative to the Earth.

13. Due to the rotation of the Sun, light waves received from opposite ends of a diameter on the Sun show equal but opposite Doppler shifts. The relative speed of rotation of a point on the end of a diameter of the Sun relative to the Earth is 2 km s^{-1}. Calculate the wavelength shift for a hydrogen line of wavelength 486·1 nm on the Earth.

Section 7: Big Bang theory

1. The graphs below are obtained by measuring the energy emitted at different wavelengths from an object at different temperatures.
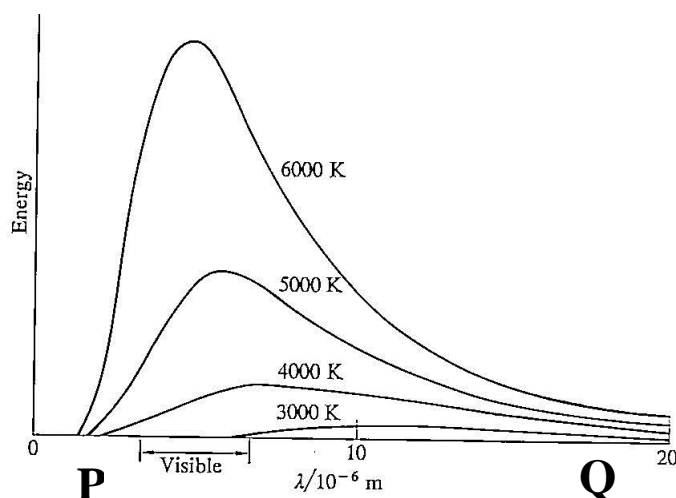
(a) Which part of the *x*-axis, P or Q, corresponds to ultraviolet radiation?

(b) What do the graphs show happens to the amount of energy emitted at a *certain* wavelength as the temperature of the object increases?

(c) What do the graphs show happens to the *total* energy radiated by the object as its temperature increases?

(d) Each graph shows that there is a wavelength λ_{max} at which the maximum amount of energy is emitted.

    (i) Explain why the value of λ_{max} decreases as the temperature of the object increases.

    The table shows the values of λ_{max} at different temperatures of the object.

Temperature /K	λ_{max} / m
6000	$4 \cdot 8 \times 10^{-7}$
5000	$5 \cdot 8 \times 10^{-7}$
4000	$7\,3 \times 10^{-7}$
3000	$9 \cdot 7 \times 10^{-7}$

(ii) Use this data to determine the relationship between temperature T and λ_{max}.

(e) Use your answer to (d) (ii) to calculate:
 (i) the temperature of the star Sirius where λ_{max} is $2 \cdot 7 \times 10^{-7}$ m
 (ii) the value of λ_{max} for the star Alpha Crucis which has a temperature of 23,000 K
 (iii) the temperature of the present universe when λ_{max} for the cosmic microwave radiation is measured as $1 \cdot 1 \times 10^{-3}$ m.
 (iv) the approximate wavelength and type of the radiation emitted by your skin, assumed to be at a temperature of 33° C.

Solutions

Revision problems – Speed

2.　　$6·8$ ms^{-1}

3.　　$1·4 \times 10^{11}$ m

4.　　181 minutes

5.　　(a)　5 ms^{-1}
　　　　(b)　35 m
　　　　(c)　10 ms^{-1}
　　　　(d)　100 m
　　　　(e)　135 m

6.　　750 ms^{-1}

7　　5 s

8.　　2 s¶

Revision problems – Acceleration

1.　　(a)　2 ms^{-2}
　　　　(b)　6 s

2.　　(a)　$2·0$ ms^{-2}
　　　　(b)　24 ms^{-1}
　　　　(c)　$6·0$ s

3.　　$0·20$ ms^{-2}

Revision problems – Vectors

1. (a) 80 km
    (b) 40 km h^{-1}
    (c) 20 km north
    (d) 10 km h^{-1} north

2. (a) 70 m
    (b) 50 m bearing 037
    (c) (i)   70 s
        (ii) 0·71 ms^{-1} bearing 037

3. (a) 6·8 N bearing 077
    (b) 11·3 N bearing 045
    (c) 6·4 N bearing 129

5. Average speed = 11 km h^{-1}
    Average velocity = 5 km h^{-1} bearing 233

6. (a) 5·1 ms^{-1}
    (b) 14·1 ms^{-1}

Section 1: Equations of motion

Equations of motion

1. 280 m

2. 51·2 m

3. 28 ms^{-1}

4. 16·7 s

5. 3·0 s

6. (a) 750 ms^{-2}
    (b) 0·04 s

7. 9·5 ms^{-2} or N kg^{-1}¶

8. (a) 0·21 ms^{-2}
    (b) 1·4 s

9. 234 m

10. (a) (i)   21·4 m
        (ii)   15·6 ms^{-1} downwards
    (b)   34·6 m¶

Motion–time graphs

1. (a)   2 ms^{-1} due north
    (b)   0 ms^{-1}
    (d)   0·75 ms^{-1}

2. (a)   4 ms^{-1} due north
    (b)   1·0 ms^{-1} due south
    (d)   1·6 ms^{-1}
    (f)   displacement 2 m due north, velocity 4 ms^{-1} due north
    (g)   displacement 2 m due north, velocity 1 ms^{-1} due south¶

3. (a)   1 ms^{-1} due north
    (b)   2 ms^{-1} due south
    (d)   1 ms^{-1}
    (f)   displacement 0·5 m due north, velocity 1 ms^{-1} due north
    (g)   displacement 0, velocity 2 ms^{-1} due south

4. (a)   2 ms^{-2} due north
    (b)   0 ms^{-2}
    (c)   4 m due north
    (d)   32 m due north¶

5. (a)   1 ms^{-2} due north
    (b)   2 ms^{-2} due south
    (d)   displacement 3 m due north, velocity   0 ms^{-1}
    (e)   displacement 2 m due north, velocity   2 ms^{-1} due south

6. (a) (i)   17·5 m due north
        (ii)   22·5 m due north
        (iii) 17·5 m due north

9. D. Note that in this question, downwards is taken to be the positive direction for vectors.

10. A. Note that in this question, upwards is taken to be the positive direction for vectors.

Section 2: Forces, energy and power

Balanced and unbalanced forces

2.   4900 N

3.   (a)   (i) $1 \cdot 5 \times 10^{-2}$ ms^{-2}
         (ii) $3 \cdot 0 \times 10^{6}$ N
     (b) $-2 \cdot 7 \times 10^{-3}$ ms^{-2}

5. $0 \cdot 02$ ms^{-2}

6.   150 N¶

7.   (a)   120 N
     (b)   20 N¶

8.   (a)   1200 N
     (b)   108 m
     (c)   2592 N

9.   (a)   (ii) $7 \cdot 7$ ms^{-2}

10. (a) $1 \cdot 78 \times 10^{3}$ kg
     (b) $6 \cdot 24 \times 10^{4}$ N¶

11. $2 \cdot 86 \times 10^{4}$ N

12. (a) $1 \cdot 96 \times 10^{3}$ N
     (b) 2.26×10^{3} N
     (c) 1.96×10^{3} N
     (d) 1.66×10^{3} N¶

13. (a)   (i) $2 \cdot 45 \times 10^{3}$ N
         (ii) $2 \cdot 45 \times 10^{3}$ N
         (iii) $2 \cdot 95 \times 10^{3}$ N
         (iv) $1 \cdot 95 \times 10^{3}$ N
     (b) $4 \cdot 2$ ms^{-2}¶

14. $51 \cdot 2$ N

15. (b) $0 \cdot 4$ s reading $37 \cdot 2$ N
           4 s to 10 s reading $39 \cdot 2$ N
           10 s to 12 s reading $43 \cdot 2$ N

16. (a) 8 ms^{-2}
    (b) 16 N

17. (a) 5·1 × 10^3 N
    (b) 2·5 × 10^3 N
    (c) (i) 700 N
        (ii) 500 N
    (d) 1·03 × 10^4 N

18. 24 m

19. (a) (i) 2 ms^{-2}
        (ii) 40 N
        (iii) 20 N
    (b) (i) 12 N¶

20. (a) 3·27 ms^{-2}
    (b) 6·54 N

Resolution of forces

1. (a) 43·3 N

2. 353·6 N

3. (a) 8·7 N
   (b) 43·5 ms^{-2}

4. 0·513 ms^{-2}

5. (a) 226 N
   (b) 0·371 ms^{-2}¶

6. 9·8 N up the slope

7. 0·735 N

8. (a) 2283 N
   (b) 2·2 ms^{-2}
   (c) 14·8 ms^{-1}

9. (a) (ii) 18 N down the slope
       (iii) 9 ms^{-2} down the slope
   (b) (i) 16 N down the slope
       (ii) 8 ms^{-2} down the slope

Work done, kinetic and potential energy

1. (a) 3·92 J
    (b) 8·9 ms^{-1}
    (c) 6·3 ms^{-1}¶

2. (a) 1080 J
    (b) 120 J¶

3. (a) 9·8 J
    (b) (i) 3·1 ms^{-1}

4. (a) 490 N
    (b) 9·8 × 10^3 J
    (c) 3·9 s¶

5. 3·0 × 10^5 W¶

6. (a) 330 N
    (b) 2·0 × 10^{-3} s

Section 3: Collisions and explosions

1. (a) 20 kg ms^{-1} to the right
    (b) 500 kg ms^{-1} downwards
    (c) 9 kg ms^{-1} to the left

2. (a) 0·75 ms^{-1} in the direction in which the first trolley was moving

3. 2·4 ms^{-1}

4. 3·0 kg

5. (a) 2·7 ms^{-1}
    (b) 0·19 J

6. 8·6 ms^{-1} in the original direction of travel

7. (a) 23 ms^{-1}

8. 8·7 ms^{-1}

9. 0.6 ms^{-1} in the original direction of travel of the 1.2 kg trolley¶

10. 16.7 ms^{-1} in the opposite direction to the first piece

11. 4 kg

12. 0.8 ms^{-1} in the opposite direction to the velocity of the man ¶

13. 1.3 ms^{-1} in the opposite direction to the velocity of the first trolley¶

14. 1.58 ms^{-1}

15. 100 N

16. 3.0×10^{-2} s

17. 2.67 ms^{-1}¶

18 (a) $+ 0.39$ kg ms^{-1} if you have chosen upwards directions to be positive; -0.39 kg ms^{-1} if you have chosen downwards directions to be positive
    (b) $+ 0.39$ N s if you have chosen upwards directions to be positive
    (c) 15.6 N downwards
    (d) 15.6 N upwards
    (e) 16.6 N upwards¶

19. (a) v before $= 3.96$ ms^{-1} downwards; v after $= 2.97$ ms^{-1} upwards
    (b) 9.9×10^{-2} s

20. (b) 0.2 s
    (c) 20 N upwards (or -20 N for the sign convention used in the graph)
    (d) 4.0 J

21. 1.25×10^{3} N towards the wall¶

22. 9.0×10^{4} N

24. (a) (i) 4.0 ms^{-1} in the direction the 2.0 kg trolley was travelling
        (ii) 4.0 kg ms^{-1} in the direction the 2.0 kg trolley was travelling

(iii) $4{\cdot}0$ kg ms^{-1} in the opposite direction the $2{\cdot}0$ kg trolley was travelling

(b) $8{\cdot}0$ N

Section 4: Gravitation

Projectiles

1. (a) $7{\cdot}8$ s
   (b) 2730 m

2. (a) $5{\cdot}0$ s
   (b) 123 m

3. (b) $24{\cdot}7$ ms^{-1} at an angle of 52.6° below the horizontal

4. (a) $v_{\text{horiz}} = 5{\cdot}1$ m s^{-1}, $v_{\text{vert}} = 14{\cdot}1$ ms^{-1}

5. (b) 50 ms^{-1} at 36.9° above the horizontal
   (c) 40 ms^{-1}
   (d) 45 m
   (e) 240 m

6. (a) 20 ms^{-1}
   (b) 20.4 m
   (c) $4{\cdot}1$ s
   (d) 142 m

7. (a) 8 s
   (b) 379 m

8. (a) $15{\cdot}6$ ms^{-1}

12. 2 s

Gravity and mass

1. $F = \dfrac{G\mathrm{m}_1\mathrm{m}_2}{r^2}$

3. $2{\cdot}67 \times 10^{-4}$ N

4. $3{\cdot}61 \times 10^{-47}$ N

5. $3 \cdot 53 \times 10^{22}$ N

6. $4 \cdot 00 \times 10^{-15}$ m

Section 5: Special relativity

Relativity – Fundamental principles

1. (a) $1 \cdot 0$ ms^{-1} north
   (b) $2 \cdot 0$ ms^{-1} south

2. (a) $0 \cdot 8$ ms^{-1} east
   (b) $2 \cdot 8$ ms^{-1} east
   (c) $2 \cdot 2$ ms^{-1} west

3. (a) $3 \cdot 0$ ms^{-1}
   (b) $2 \cdot 0$ ms^{-1}

4. A = Einstein's; B = same; C = zero; D = velocity; E = speed of light; F = slow; G = shortened

5. 2000 km h^{-1}

6. (a) No
   (b) Yes

7. 3×10^8 ms^{-1}

8. (a) 100 s
   (b) 100 s

9. (a) 3×10^8 ms^{-1}
   (b) 3×10^8 ms^{-1}

10. (a) $0 \cdot 3 \times 10^8$ ms^{-1}
    (b) $1 \cdot 5 \times 10^8$ ms^{-1}
    (c) $1 \cdot 8 \times 10^8$ ms^{-1}
    (d) $2 \cdot 4 \times 10^8$ ms^{-1}

11. (a) c
    (b) $0 \cdot 67$ c
    (c) $0 \cdot 5$ c
    (d) $0 \cdot 33$ c

Relativity – Time dilation

1. $$t' = \frac{t}{\sqrt{1-(\frac{v^2}{c^2})}}$$

2. (a)   21·2 h
    (b)   15·1 year
    (c)   1043 s
    (d) $1·32 \times 10^{-4}$ s
    (e) $2·10 \times 10^{8}$ ms^{-1}
    (f) $9·15 \times 10^{7}$ ms^{-1}

3. (a)   11.20 am
    (b)   11.20 am

4. 17·1 billion years

5. 9·69 s

6. $3·9 \times 10^{-4}$ s

7. $2·1 \times 10^{8}$ ms^{-1} or 0·70 c

8. $2·90 \ 10^{8}$ ms^{-1} or 0·97 c

9. $2·60 \times 10^{8}$ ms^{-1}

Relativity – Length contraction

1. $l' = l \ \sqrt{(1 - v^2/c^2)}$

2. (a)   4·71 m
    (b)   11·2 m
    (c)   0·227 km
    (d)   160 mm
    (e) $1·55 \times 10^{8}$ ms^{-1}
    (f) $1·25 \times 10^{8}$ ms^{-1}

3. 16 m

4. 0·872 m

5. 267 m

6. 0·92 km

7. $2·60 \times 10^8$ ms^{-1}

8. $2·19 \times 10^8$ ms^{-1}

9. $4·23 \times 10^7$ ms^{-1} or 0.14 c

Relativity questions

1. (b) $1·67 \times 10^{-6}$ s
    (c) 144 m

2. (a) 0·31 of a year
    (c) $8·97 \times 10^{15}$ m

3. (a) $1·84 \times 10^{-7}$ s
    (b) 54·6 m or 54·7 m

4. (a) 120 m
    (b) 72 m

5. (a) 5 s
    (b) 9·22 s

6. 0·8 c

7. (a) 447 m
    (b) $1·49 \times 10^{-6}$ s

8. (a) 0·52 c
    (b) $2·55 \times 10^8$ s
    (c) $2·18 \times 10^8$ s

9. (a) $2·60 \times 10^{-7}$ s
    (b) 77·6 m
    (c) 7·75 m or 7·76 m

Section 6: The expanding universe

The Doppler effect and redshift of galaxies

1. A = higher; B= lower; C = Doppler; D = effect

2. (a) $f_0 = f_s \dfrac{v}{(v - v_s)}$

    (b) $f_0 = f_s \dfrac{v}{(v + v_s)}$

3. (a)   412 Hz
    (b)   389 Hz
    (c)   800 Hz
    (d)   1035 Hz
    (e)   20 ms^{-1}
    (f)   60 ms^{-1}

5. (a)   1063 Hz
    (b)   944 Hz

6. (a)   216 Hz
    (b)   186 Hz

7. 14·5 ms^{-1}

8. 466 Hz

9. 556 Hz, 525 Hz

10. (a)   1·07 m
    (b)   1·2 m

11. (a)   971 Hz
    (b)   1030 Hz

12. 37·8 m s^{-1}

13. (a)   354 kHz
    (b)   Decrease – denominator is larger
    (c)   345 kHz

14. (b)   1569 Hz
    (c)   1437 Hz

15. 21·3 ms^{-1}

16. (b)   2106 Hz
    (c)   2302 Hz

17. 154 s

18. 120 ms^{-1}

19. A = longer; B = red; C = shorter; D = blue; E = away

20. (a) $1\cdot01 \times 10^{-1}$
    (b) $5\cdot07 \times 10^{-2}$
    (c)   525 nm
    (d)   682 nm
    (e)   434 nm
    (f)   365 nm

Hubble's law

1. (a) $9\cdot46 \times 10^{15}$ m
   (b) $4\cdot73 \times 10^{17}$ m
   (c) $9\cdot46 \times 10^{20}$ m
   (d) $1\cdot51 \times 10^{26}$ m

2. (a) $1\cdot52 \times 10^{-5}$ light years
   (b) $4\cdot2$ light years
   (c) $5\cdot19 \times 10^{7}$ light years

3.

v / ms^{-1}	d / m	z
$1\cdot70 \times 10^{5}$	$7\cdot10 \times 10^{22}$	$5\cdot67 \times 10^{-4}$
$4\cdot54 \times 10^{6}$	$1\cdot89 \times 10^{24}$	$1\cdot51 \times 10^{-2}$
$1\cdot70 \times 10^{6}$	$7\cdot08 \times 10^{23}$	$5\cdot667 \times 10^{-2}$
$2\cdot21 \times 10^{6}$	$9\cdot21 \times 10^{23}$	$7\cdot37 \times 10^{-3}$

4. (a) $7\cdot37 \times 10^{-2}$
   (b) $2\cdot21 \times 10^{7}$ ms^{-1}
   (c)   Away

5. (a) $1\cdot49 \times 10^{7}$ ms^{-1}
   (b) $6\cdot21 \times 10^{24}$ m

6. (a) $2\cdot22 \times 10^{7}$ ms^{-1}
   (b) $9\cdot25 \times 10^{24}$ m

7. (a) 8×10^{-2}
    (b) 410 nm

8. (a) $3 \cdot 0 \times 10^7 \text{ ms}^{-1}$
    (b) $1 \cdot 25 \times 10^{25}$ m, $1 \cdot 32 \times 10^9$ light years

9. $2 \cdot 27 \times 10^7 \text{ ms}^{-1}$

10. (b) $4 \cdot 55 \times 10^{14}$ Hz

11. (a) $1 \cdot 23 \times 10^7 \text{ ms}^{-1}$
    (b) 542 million light years

12. $1 \cdot 83 \times 10^6 \text{ m s}^{-1}$

13. $3 \cdot 24 \times 10^{-12}$ m

Section 7: Big Bang theory

1. (a) P
    (b) Energy emitted increases
    (c) Increases
    (d) (ii) $T \, \lambda_{\max} = 2 \cdot 9 \times 10^{-3} \text{ m K}$
    (e) (i) $T = 11,000$ K
         (ii) $\lambda_{\max} = 1 \cdot 3 \times 10^{-7}$ m
         (iii) $T = 2 \cdot 6 \text{ K}$
         (iv) $\lambda = 9 \cdot 5 \times 10^{-6}$ m, infrared