3. Motion and Forces Problem Set

3.1 KINEMATICS

3.1.1 Exercises

For this section of the problem set, you should try the exercises without looking at the solutions. The solutions are there if you get stuck and you should also use it to understand how to present your work.

E1 Distinguish whether the following statements describe speed, velocity, distance, or displacement.

(a) The ship sailed south-west for 200 km.
(b) I averaged 11 km h^{-1} during the marathon.
(c) The snail crawled at 2 mm s^{-1} along the straight edge of a bench.
(d) The sales representative's round trip was 420 km.

E2 Explain whether the speedometer of a car registers its speed or velocity.

E3 A student walks 3.0 km due north, and then 4.0 km due east. By drawing a vector diagram showing the route, calculate

(a) the total distance travelled, [7.0 km]
(b) the displacement of the student. [5.0 km at 53° east of north]

E4 A sprinter, starting from blocks, reaches his full speed of 9.0 m s^{-1} in 1.5 s. Determine the sprinter's average acceleration. [6.0 m s^{-2}]

E5 A railway train, travelling along a straight track, takes 1.5 minutes to come to rest from a speed of 115 km h^{-1}. Determine the average acceleration of the train. [−0.35 m s^{-2}]

E6 The Earth takes one year to orbit in a circle around the Sun at a distance of 1.5×10^{11} m. Calculate the average speed and average velocity of the Earth over one year.
[30 000 m s^{-1}, 0 m s^{-1}]

E7 A racing car accelerates for 10 s through three gear changes with the following average speeds:

20 m s^{-1} for 2.0 s

40 m s^{-1} for 2.0 s

60 m s^{-1} for 6.0 s

Determine the average speed of the car during the 10 s acceleration. [48 m s^{-1}]

3.1.2 Practice

P1 A student walks 8.0 km south-east and then 10 km due west.

(a) Draw a vector diagram showing the route.

(b) Calculate, using trigonometry, the displacement of the student.

P2 A railway train travels at a constant speed of 60 km h^{-1}. It moves east for 40 min, then 45° west of north for 30 min.

Determine the average velocity of the train.

3.2 DESCRIBING MOTION WITH GRAPHS

3.2.1 Exercises

E8 The displacement of a racing car at different times as it travels along a straight track during a time trial is shown below.

displacement / m	0	85	170	255	340
time / s	0	1.0	2.0	3.0	4.0

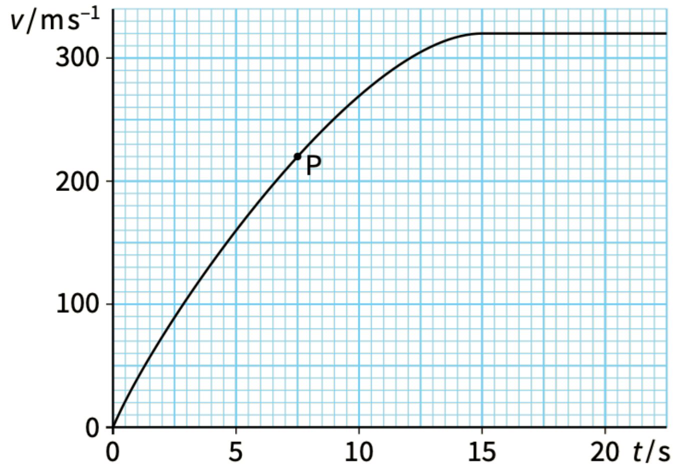
(a) Draw a displacement-time graph for this motion.
(b) Determine the velocity of the car. [85 m s^{-1}]

E9 The velocity of a motorcyclist at different times as it travels along a straight road during a time trial is shown below.

velocity / m s^{-1}	0	15	30	30	20	10	0
time / s	0	5	10	15	20	25	30

(a) Draw a velocity-time graph for this motion.
(b) Determine the motorcyclist's acceleration during the first 10 s. [3.0 m s^{-2}]
(c) Determine the motorcyclist's acceleration during the last 15 s. [−2.0 m s^{-2}]
(d) Determine the total distance travelled during the time trial. [525 m]
(e) Describe the motion of the motorcycle.

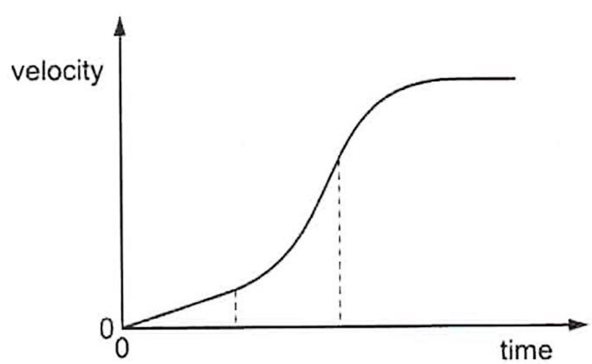
E10 The graph represents the motion of an object moving with varying acceleration.



Estimate the object's acceleration at P. [20 m s^{-2}]

3.2.2 Practice

P3 The graph shows how the velocity of a racing car changes with time.



Which statement describes the acceleration? (2009 P1 Q3)

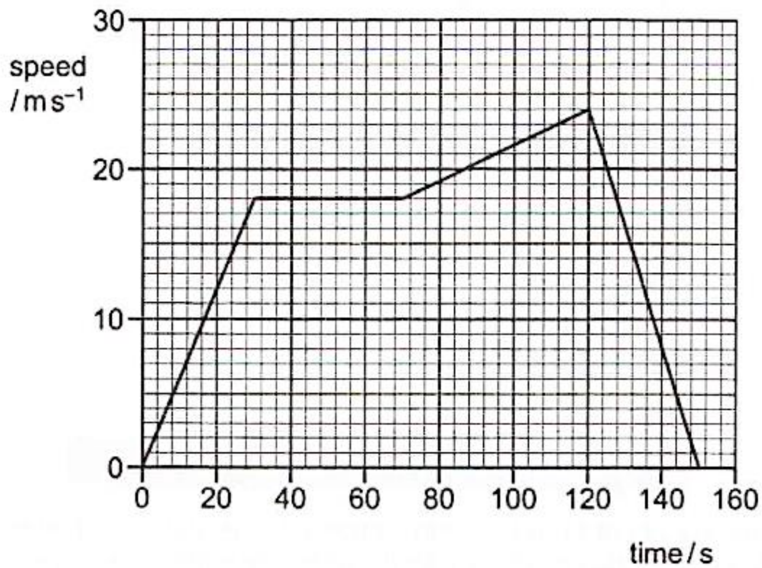
A A constant positive acceleration is followed by an acceleration increase and then a negative acceleration.

B The acceleration increases positively in the first two sections and then decreases to zero.

C The acceleration is positive at the start, increases, then decreases to zero.

D The acceleration starts from zero, increases, then decreases to zero.

P4 The graph shows how the speed of a vehicle varies over a period of time of 150 s.

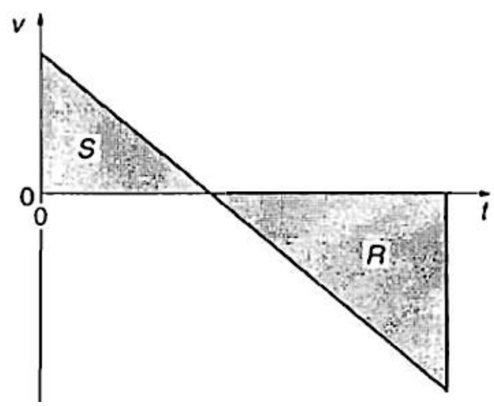


What is the average speed of the vehicle over the 150 s? (2015 P1 Q2)

A 10 m s^{-1} **B** 12 m s^{-1} **C** 14 m s^{-1} **D** 16 m s^{-1}

P5 A stone is thrown upwards from the top of a cliff. After reaching its maximum height, it falls past the cliff-top and into the sea.

The graph shows how the vertical velocity v of the stone varies with time t after being thrown upwards. R and S are the magnitudes of the areas of the two triangles.

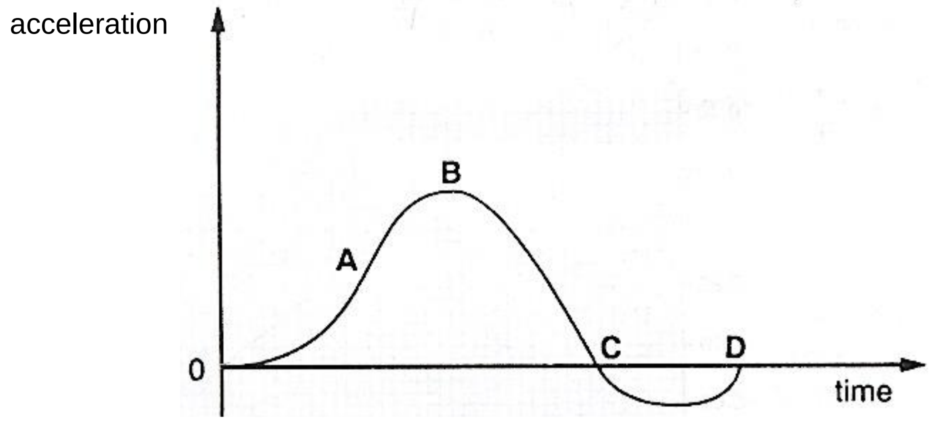


What is the height of the cliff-top above the sea?

A R **B** S **C** $R + S$ **D** $R - S$

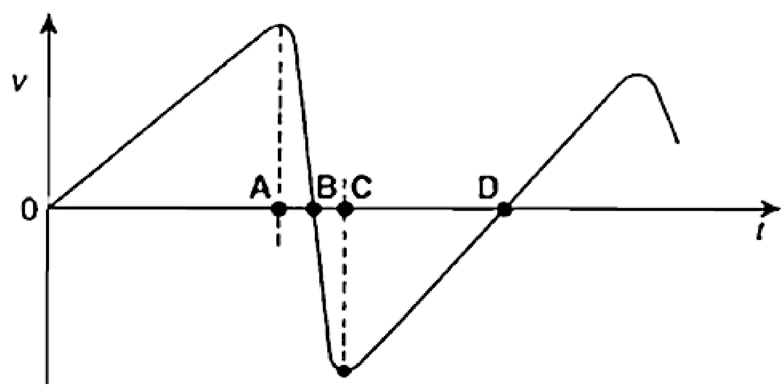
P6 A car is travelling along a straight road. The graph shows the variation with time of its acceleration during part of the journey.

At what point on the graph does the car have its greatest velocity?



P7 The graph shows the variation with time *t* of the velocity *v* of a bouncing ball, released from rest. Downward velocities are taken as positive.

At which time does the ball reach its maximum height after bouncing?



P8 A stone falls freely from rest to the ground. The effects of air resistance on the stone are negligible.

The stone travels 0.75 of the total distance to the ground in the last second of its fall.

What is the time of the fall? (2014 P1 Q4)

A 1.25 s **B** 1.50 s **C** 1.67 s **D** 2.00 s

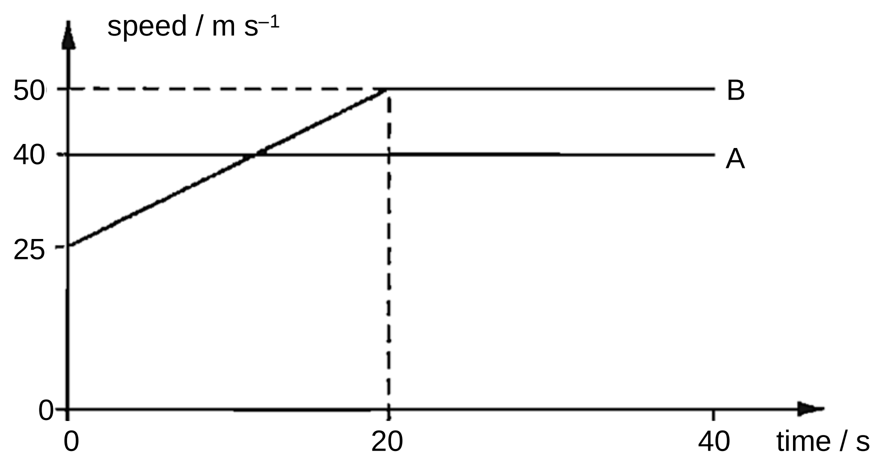
P9 A car accelerates uniformly from rest along a level road. The effects of air resistance on the car are negligible.

The car travels 12 m in the time between 1 s and 2 s after starting.

How far does it travel in the time between 3 s and 4 s after starting? (2013 P1 Q3)

A 28 m **B** 35 m **C** 48 m **D** 64 m

P10 The graph below shows the speeds of two cars A and B which are travelling in the same direction over a period of time of 40 s. Car A, travelling at a constant speed of 40 m s^{-1}, overtakes car B at time t = 0. In order to catch up with car A, car B immediately accelerates uniformly for 20 s to reach a constant speed of 50 m s^{-1}.



Determine

(a) the distance travelled by car A in the first 20 s, [1]

(b) the acceleration of car B in the first 20 s, [1]

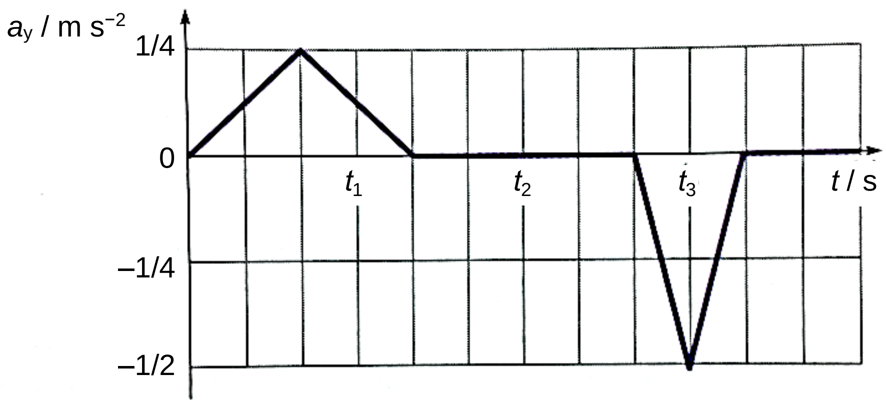
(c) the distance travelled by car B in the first 20 s, [2]

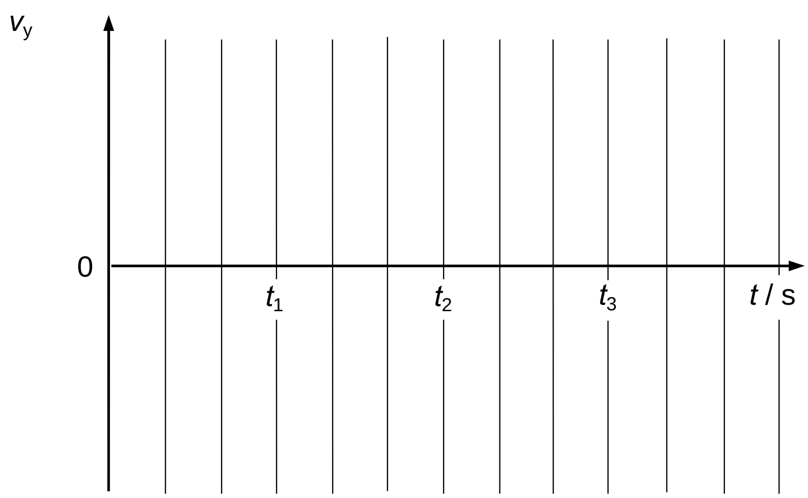
(d) the additional time it takes for car B to catch up with car A, [2]

(e) the distance each car has travelled since t = 0 when car B catches up with car A, and [1]

(f) the maximum distance between the cars before car B catches up with car A. [3]

P11 An elevator starts at rest on the ninth floor. At t = 0, a passenger pushes a button to go to another floor. The graph below shows the acceleration a_y of the elevator as a function of time. Assume positive is upwards acceleration.





(a) Sketch a graph of velocity v_y of the elevator with time.

(b) State and explain if the elevator has gone to a higher or lower floor.

3.3 UNIFORMLY ACCELERATED LINEAR MOTION

3.3.1 Exercises

E11 A car is initially stationary. It has a constant acceleration of 2.0 m s^{-2}. Calculate

(a) the velocity of the car after 10 s, [20 m s^{-1}]
(b) the distance travelled by the car at the end of 10 s, and [100 m]
(c) the time taken by the car to reach a velocity of 24 m s^{-1}. [12 s]

E12 A train accelerates steadily from 4.0 m s^{-1} to 20 m s^{-1} in 100 s. Calculate

(a) the acceleration of the train, [0.16 m s^{-2}]

(b) the average velocity of the train, and[12 m s^{-1}]

(c) the distance travelled by the train in the 100 s. [1200 m]

E13 An egg falls off a table. The floor is 0.80 m from the top of the table. Calculate

(a) the time taken to reach the ground, and [0.40 s]

(b) the velocity of impact with the ground. [4.0 m s^{-1}]

E14 In Section 2.1, we looked at how a motion sensor can be used to measure the speed and position of a moving object. Suggest how a motion sensor could be used to determine *g*.

3.3.2 Practice

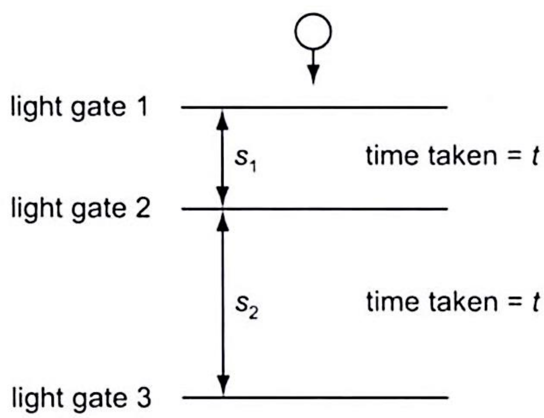
P12 A man stands on the edge of a cliff. He throws a stone upwards with a velocity of 19.6 m s^{-1} at time t = 0. The stone reaches the top of its trajectory after 2.00 s and then falls towards the bottom of the cliff. Air resistance is negligible.

Which row shows the correct velocity v and acceleration a of the stone at different times?

	t / s	v / m s^{-1}	a / m s^{-2}
A	1.00	9.81	9.81
B	2.00	0	0
C	3.00	9.81	–9.81
D	5.00	–29.4	–9.81

(2009 P1 Q4)

P13 An object falls freely with constant acceleration a from above three light gates. It is found that it takes a time t to fall between the first two light grates a distance of s_1 apart. It then takes an additional time, also t, to fall between the second and third light gates a distance s_2 apart.



What is the acceleration in terms of s_1, s_2 and t?

A $\dfrac{(S_2 - S_1)}{t^2}$ **B** $\dfrac{(S_2 - S_1)}{2t^2}$ **C** $\dfrac{2(S_2 - S_1)}{3t^2}$ **D** $\dfrac{2(S_2 - S_1)}{t^2}$

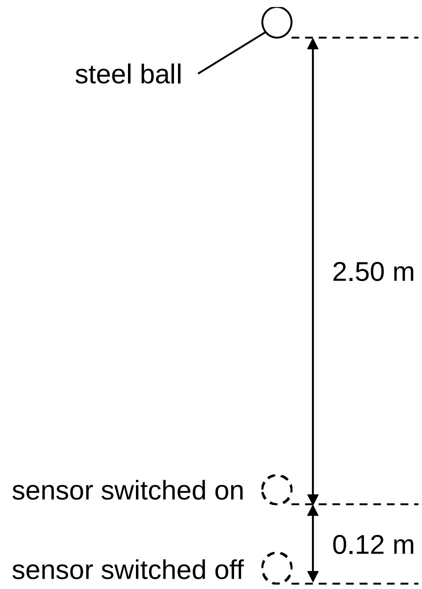
(2010 P1 Q5)

P14 A parachutist after bailing out fell 50 m without air resistance. When the parachute opened, the acceleration was 2.0 m s^{-2} pointing upward. He reached the ground with a speed of 3.0 m s^{-1}.

(a) Calculate the time the parachutist was in the air.

(b) Calculate the height at which he bailed out.

P15 When a photograph is taken with a digital camera, the sensor of the camera captures light from the subject over a short period of time. During this period, the sensor is switched on to start the capture and switched off to stop the capture.



Before the photograph is taken, the ball falls, from rest, 2.50 m. During the time interval *T* that the sensor is switched on, the ball falls a further 0.12 m, as illustrated.

Air resistance is negligible.

(a) Calculate

(i) the speed of the ball after falling 2.50 m, and [2]

(ii) the time T in which the ball falls a further 0.12 m. [2]

(b) The time interval *T* for which the sensor is switched on is stated on the camera as 1/60 s. Comment on whether the stated value is correct. [2]

3.4 MASS AND LINEAR MOMENTUM

3.4.1 Exercises

E15 An insect of mass 4.5 mg, flying with a speed of 0.12 m s^{-1}, encounters a spider's web, which brings it to rest in 2.0 ms.

Calculate the change of momentum of the insect.

3.5 LAWS OF MOTION

3.5.1 Exercises

E16 An aircraft is flying straight and level with constant velocity relative to the ground.

What is the resultant force action on the aircraft?

A The weight of the aircraft.

B The resultant of the air resistance and the thrust of the engines.

C The resultant of the air resistance and the weight of the aircraft.

D Zero.

E17 A constant mass undergoes uniform acceleration.

Which of the following is a correct statement about the resultant force acting on the mass?

A It increases uniformly with respect to time.

B It is constant but not zero.

C It is proportional to the displacement from a fixed point.

D It is proportional to the velocity. (2001 P1 Q4)

E18 A parachutist of mass 80 kg is descending at a constant velocity of 3.0 m s^{-1}.

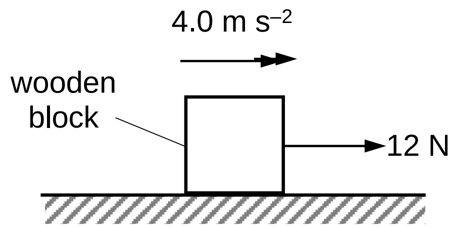
What is the resultant force acting on the parachutist?

(Assume that the acceleration of free fall to be 10 m s^{-2}.)

A 800 N upwards **B** zero

C 240 N downwards **D** 360 N downwards

E19 A horizontal force of 12 N is applied to a wooden block of mass 0.60 kg on a rough horizontal surface as shown.



The block accelerates at 4.0 m s^{-2}.

What is the magnitude of the frictional force acting on the block?

A 2.4 N **B** 9.6 N **C** 14 N **D** 16 N

E20 A block of mass m rests on the surface of an inclined plane of angle θ.

Assuming that frictional force R is constant, what is the acceleration of the block down the plane when it is released?

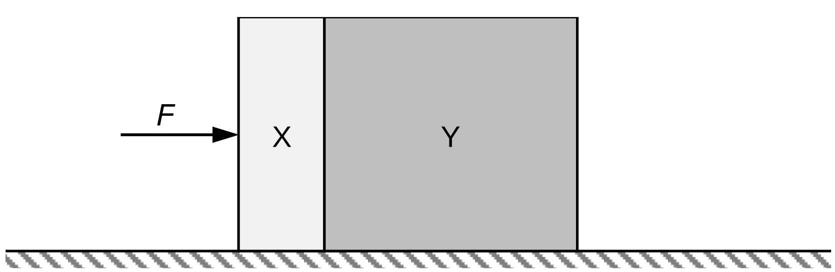
A $g+\frac{R}{m}$ **B** $g-\frac{R}{m}$ **C** $g\sin\theta+\frac{R}{m}$ **D** $g\sin\theta-\frac{R}{m}$

E21 Determine the tension in the cable of a lift of mass 500 kg if the lift is

(a) moving downwards and accelerating at a rate of 3.0 m s^{-2},

(b) moving downwards and slowing down at a rate of 2.0 m s^{-2}.

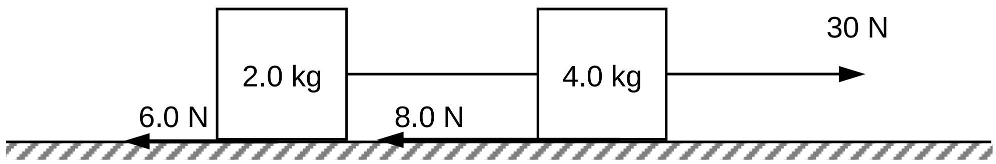
E22 Two blocks, X and Y, of masses m and $3m$ respectively, are accelerated along a smooth horizontal surface by a force F applied to block X as shown.



What is the magnitude of the force exerted by block X on block Y during this acceleration?

A $\frac{F}{4}$ **B** $\frac{F}{3}$ **C** $\frac{F}{2}$ **D** $\frac{3F}{4}$

E23 Two blocks are attached together by a horizontal string. The blocks are being pulled across the table by a horizontal force of 30 N.



The 2.0 kg block has a 6.0 N frictional force exerted on it by the table while the 4.0 kg block has a 8.0 N frictional force acting on it.

Determine

(a) the resultant force acting on the entire two-block system,

(b) the acceleration of the system of two blocks,

(c) the force acting on the 4.0 kg block by the connecting string.

E24 A stream of water from a hose flows horizontally at a speed of 5.0 m s^{-1}. The stream strikes a brick wall and reflects with the same initial speed. The flow rate of the water is 2.0 kg s^{-1}.

Determine the magnitude of the force exerted on the wall by the water.

E25 Water of density 1000 kg m^{-3} is ejected from the nozzle of a hose 1.0 cm in diameter at a speed of 50 cm s^{-1}.

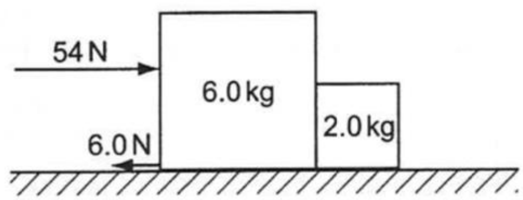
Determine the force exerted on the hose by the water.

3.5.2 Practice

P16 A person of mass m sits in a car which is accelerating horizontally at 0.50 g where g is the acceleration of free fall. What is the magnitude of the total force F exerted by the car's seat on the person?

A $0.50mg$ **B** $1.0mg$ **C** $1.1mg$ **D** $1.5mg$

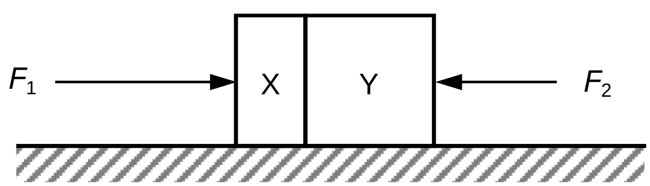
P17 A force of 54 N pushes two touching blocks of mass 6.0 kg and 2.0 kg along a flat surface. The frictional force between the blocks and the surface is 6.0 N.



What is the magnitude of the resultant force on the 6.0 kg mass? (2010 P1 Q7)

A 12 N **B** 36 N **C** 45 N **D** 48 N

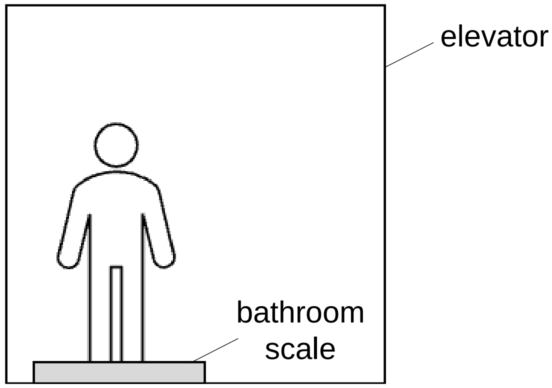
P18 Two blocks, X and Y, of masses m and $2m$ respectively, are placed on a horizontal frictionless surface.



With horizontal forces, F_1 and F_2 acting on X and Y respectively ($F_1 > F_2$), the blocks are accelerating uniformly.

Determine the expression, in terms of F_1 and F_2, of the force exerted on Y by X.

P19 A 700 N person stands on a bathroom scale placed on the floor of an elevator.



(a) Determine the contact force between the person and the bathroom scale if the elevator is

(i) accelerating upwards at 1.80 m s^{-2},

(ii) accelerating downwards at 1.80 m s^{-2},

(iii) accelerating downwards at 9.81 m s^{-2}.

(b) Discuss the readings on the bathroom scale for the situations in **(a)(iii)**.

P20 **(a)** A car of mass 750 kg is travelling at 25 m s^{-1} along a horizontal road. The brakes are applied and the car is brought to rest by an average resistive force *F*. The car has an average deceleration of 4.8 m s^{-2}.

(i) Show that the resistive force acting on the car is 3600N. [1]

(ii) Calculate the distance travelled by the car during this deceleration. [2]

(iii) Describe, in terms of Newton's third law, the horizontal forces acting on the tyres of the car and on the road. [2]

(b) The car in **(a)** now travels at 25 m s^{-1} down a slope where the angle to the horizontal is 10°. The car is brought to rest by applying the brakes. The same resistive force of 3600 N acts on the car.

(i) Explain why the distance the car travels before coming to rest is greater than in **(a)**. [1]

(ii) Calculate the deceleration of the car. [2]

(2010 P2 Q1)

P21 A helicopter has blades of diameter 5.0 m is hovering above the ground. Its blades are rotating so that they are pushing air downwards at a speed of 18 m s^{-1}. The density of the surrounding air can be taken as 1.02 kg m^{-3}.

The upward force acting on the blades is

A 360 N **B** 1400 N **C** 6500 N **D** 26000 N

P22 A machine gun fires bullets at a rate of 360 per minute. The bullets have a mass of 20 g and a speed of 500 m s^{-1}.

Calculate the average force exerted by the gun on the person holding it.

P23 The motor-propeller assembly of a boat comprises a propeller that is driven by motor.

The propeller sends a column of water of cross-sectional area 0.030 m^2 at a speed of 8.0 m s^{-1} (relative to the boat) in the direction opposite to the motion of the boat.

The density of water is 1000 kg m^{-3}.

Calculate

(a) the volume flow rate at which water is propelled backwards,

(b) the rate of change of momentum of the water,

(c) the force exerted by the motor-propeller assembly on the boat.

Numerical Answers for Practice Questions

1b)	7.1 km 38° west of south			2)	24 km h^{-1} at 48° north of east
10a)	800 m	b)	$1.25\ \mathrm{m\ s^{-2}}$	c)	$750\ \mathrm{m}$
d)	t = 5.0 s	e)	1000 m	f)	$90\ \mathrm{m}$
14a)	17.4 s	b)	293 m		
15ai)	$7.00\ \mathrm{m\ s^{-1}}$	ii)	0.0169 s	b)	1.4%
19ai)	828 N	ii)	572 N	iii)	0 N
20ai)	3600 N	ii)	$65\ \mathrm{m}$	bii)	$3.1\ \mathrm{m\ s^{-2}}$
22)	60 N	23a)	$0.24\ \mathrm{m^3\ s^{-1}}$	b)	$1900\ \mathrm{N}$