Page 151 Test yourself on prior knowledge

1 a) W = mg

= 57 kg × 9.8 N kg^{-1}

= 559 N

b) W = mg

= 57 kg x 3.7 N kg-1

= 211 N

2 a) i) It remains at rest.

ii) It continues to move at 3 m s^{-1}.

iii) It accelerates.

iv) It decelerates.

v) It decelerates.

vi) It changes direction.

b) i) a = 0

ii) a = 0

iii) a = 10 N ÷ 2 kg = 5 m s^{-2} to the right

iv) a = 10 N ÷ 2 kg = 5 m s^{-2} to the left

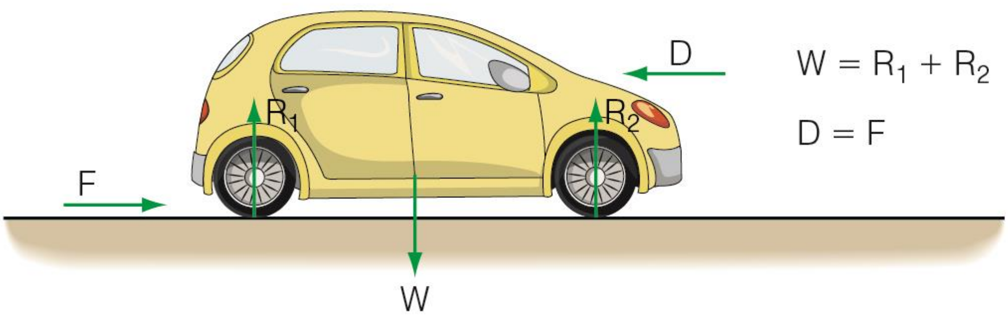
v) a = (10 N – 8 N) ÷ 2 kg = 1 m s^{-2} to the left

vi) a = 5 m s^{-2} downwards

3 300 N on Tony to the left.

Pages 154–155 Test yourself

1 a) The weight, W, is balanced by the reaction forces, R_1 and R_2, from the back and front wheels. The drag and friction forces, D, balance the forwards push from the road on the car.



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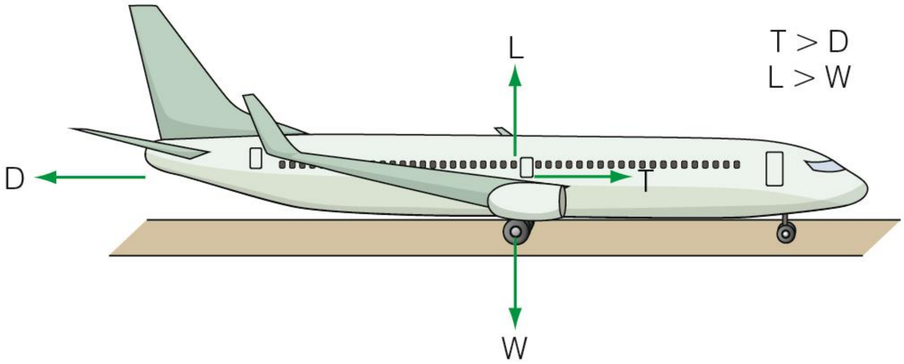
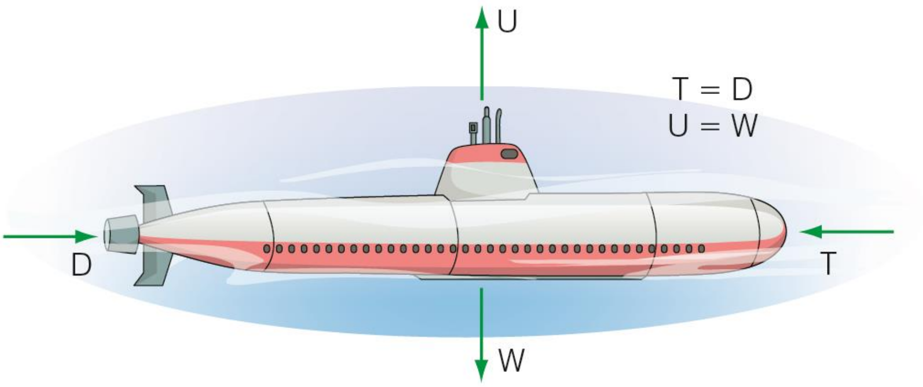
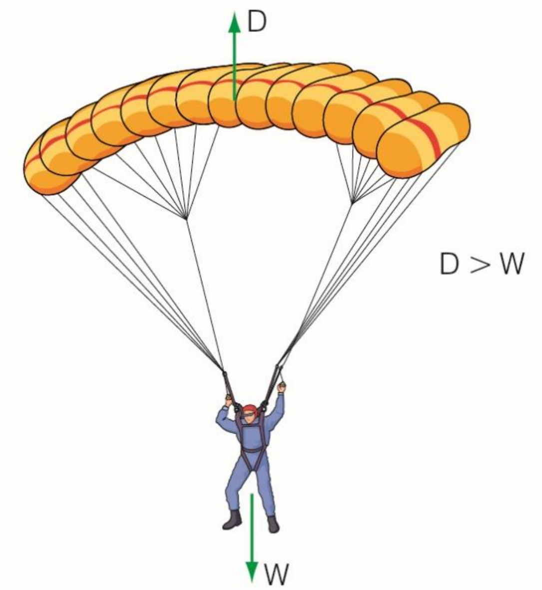
b) The thrust from the engines, T, is greater than the drag forces D. The lift on the plane, L, is greater than the plane's weight, W. The plane accelerates upwards as well as horizontally.



c) The thrust from the propellers, T, balances the drag forces, D. The upthrust on the submarine, U, balances the submarine's weight, W.



d) The drag on the parachute, D, is greater than the weight of the skydiver, W. The skydiver is decelerating – she is moving downwards, but the acceleration is upwards.



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2 a) i) R = W because the lift moves at constant speed.

So R $= 62 \text{ kg} \times 9.8 \text{ m s}^{-2}$

$= 608 \text{ N}$

ii) Overall force on passenger = W – R = m a (down positive)

R $= W - m a$

$= 608 \text{ N} - 62 \text{ kg} \times 2.0 \text{ m s}^{-2}$

$= 504 \text{ N}$

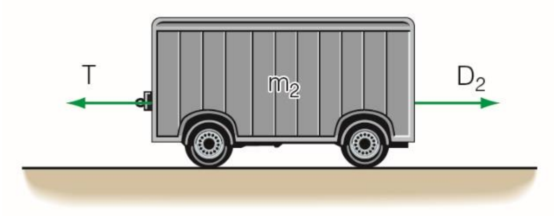
b) When the lift accelerates upwards the upwards force on the passenger is greater than their weight. The passenger is used to feeling a reaction force equal to their weight, which gives them the sensation of weight. So when the reaction is larger they feel heavier.

3 a) $F - D_1 - D_2 = (m_1 + m_2)\, a$

$2400 \text{ N} - 1000 \text{ N} - 600 \text{ N} = 1400 \text{ kg} \times a$

$a = \frac{800 \text{ N}}{1400 \text{ kg}}$

$= 0.57 \text{ m s}^{-2}$



b) The tension acts to accelerate the trailer.

So $T - D_2 = m_2 a$

$T = D_2 + m_2 a$

$= 600 \text{ N} + 450 \text{ kg} \times 0.57 \text{ m s}^{-2}$

$= 857 \text{ N}$

Alternative/check: the tension acts on the truck.

So $F - D_1 - T = m_1 a$

$T = F - D_1 - m_1 a$

$= 2400 \text{ N} - 1000 \text{ N} - 950 \text{ kg} \times 0.57 \text{ m s}^{-2}$

$= 857 \text{ N}$

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4 a) i) $a_1 = \frac{v-u}{t}$

$= \frac{5 \text{ m s}^{-1}}{2 \text{ s}}$

$= 2.5 \text{ m s}^{-2}$

ii) $a_2 = \frac{v-u}{t}$

$= \frac{(12-10.5) \text{ m s}^{-1}}{2 \text{ s}}$

$= 0.75 \text{ m s}^{-2}$

b) $F = m a_1$

$= 1200 \text{ kg} \times 2.5 \text{ m s}^{-2}$

$= 3000 \text{ N}$

c) $F - D = m a_2$

$D = F - m a_2$

$= 3000 \text{ N} - 1200 \text{ kg} \times 0.75 \text{ m s}^{-2}$

$= 2100 \text{ N}$

d) $F = m a_3$

$a_3 = \frac{F}{m}$

$= \frac{3000 \text{ N}}{1450 \text{ kg}}$

$= 2.07 \text{ m s}^{-2}$

Page 158 Test yourself

5 a)

b) The paired force to R is the contact force the dog exerts on the Earth. The paired force with W, is the gravitational pull of the dog on the Earth.

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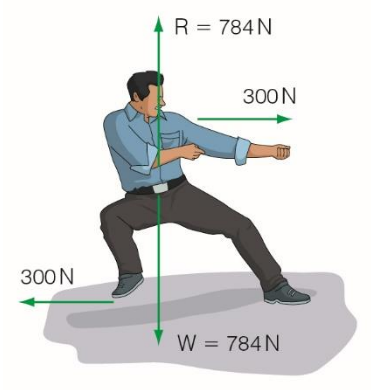
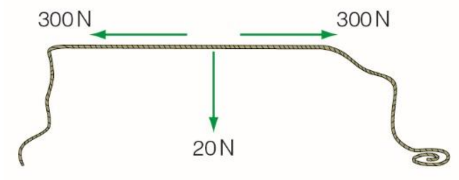
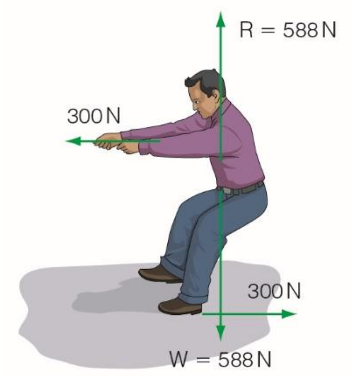
6 a) i) From Table 9.1, Alan's mass = 80 kg so W = 80 × 9.8 N/kg = 784 N



ii) From Table 9.1, mass of rope = 2 kg so W = 2 × 9.8 N/kg = 20 N (to 2 sf)



iii) From Table 9.1, Ben's mass = 80 kg so W = 60 × 9.8 N/kg = 588 N



b) There are nine Third Law pairs:

- Alan has 4 forces with pairs: Earth/Alan (gravity); 2 surface/Alan pairs (vertical and horizontal); rope/Alan.
- Ben has 4 forces with pairs as above.
- The rope has 3 forces with pairs but 2 are shared with Alan and Ben and have already been counted, leaving only Earth/rope (gravity).
- The Earth shares 5 paired forces – two with each of the men and one with the rope – and all have already been counted.

7 a) There needs to be friction between the foot and ground so that the ground can push the foot forwards when the foot pushes the ground.

b) You push the water backwards; it pushes you forwards.

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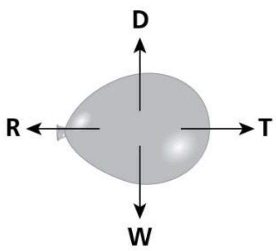
8 The balloon pushes air out backwards so the air pushes the balloon forwards by Newton's third law: force *T* on the diagram. Once the air resistance, *R* is equal to *T*, then the total horizontal force is zero and the horizontal component of the balloon's speed remains constant. [The balloon can also fall at a constant speed if its weight is balanced by the drag force D.]



9 The key to the three questions is to remember that resultant force = mass x acceleration

- **a)** The acceleration can be zero if a force is balanced by another (or others).
- **b)** A driving force might be opposed by an increasing drag force, continuously reducing the resultant force and thus the acceleration
- **c)** This might happen as a rocket takes off; the mass of the rocket decreases as it uses fuel, so the same driving force accelerates the rocket faster as its mass decreases.

10 a) The forces act on the body in such a way that each is equal to the vector sum of the others – they would form a closed triangle when drawn consecutively.

- **b)** When the 7 N force is removed, the unbalanced force is 7 N.
  So the mass accelerates at 1.4 m s^{-2}, in the opposite direction to the original 7 N force.

11 The man exerts a gravitational force of 90 kg × 9.8 N kg^{-1} = 880 N on the Earth, whether he is in contact with the Earth or not.

Pages 159–161 Activities

9.15 Investigating tension

- **a)** 5 N
- **b)** 5 N
- **c)** 5 N

It is a common mistake to think that answer a) should be 10 N. But the situation is just the same as part b) and c) – the tension in the string on both sides of the forcemeter in parts b) and c) is also 5 N.

9.16 Balanced forces

- **a)** A little more than 2 N. If *T* = tension in the string, considering forces on lower pulley block gives 2*T* = 4 N + weight of the lower pulley block.
- **b)** Taking weight of trolley as 10 N, resolving along the slope and ignoring friction:

  T = 3N = 10 N sin θ

  ⇒ sin ϑ = 0.3 and θ = 18°

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9.17 Acceleration

a) The ball initially stays where it is. So relative to the trolley it appears to hang backwards.

Trolley accelerates at 2 N /1 kg = 2 ms^{-2}

When ball is at maximum deflection, $T\cos\vartheta = mg$ and $T\sin\vartheta = ma$ where T is the tension in the string and m is the mass of the ball:

$$\frac{T\sin\theta}{T\cos\theta} = \frac{ma}{mg}$$

$$\tan\theta = \frac{a}{g} = \frac{2}{10}$$

So maximum angle of deflection: 11° (or 12^0 if you take g to be 9.8 N kg^{-1})

The trolley stops. The ball keeps moving until the string stops it. So relative to the trolley the ball goes forwards, and then swings backwards and forwards, until it has dissipated its KE.

b) $s = ut + ½ at^2$ with u = 0 gives

a = 5.9 m s^{-2}

The force that produces this acceleration is the component of the trolley's weight that acts down the slope and that previously balanced the tension of 2.5 N in the string so, using

m = F/a gives

m = 0.42 kg

c) C extends 12 cm – this accelerates a mass of 3 kg

B extends 8 cm – this accelerates a mass of 2 kg

A extends 4 cm – this accelerates a mass of 1 kg

9.18 *F = ma*

If the length of the card, *l*, is also measured, then the time it takes to pass through the first light gate can be used to calculate the initial speed, *u*. The time it takes to pass through the second gate will give the final speed, *v*. Using these with the interval between the timed measurements, *t*, allows the acceleration, *a*, to be calculated using $v = u + at$

The total mass being accelerated is 1.0 kg, as the 1 N weight has a mass of 0.1 kg. Therefore:

a = 1.0 m s^{-2}

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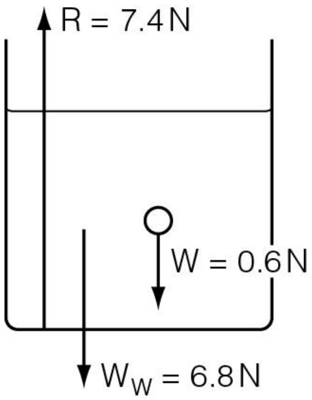
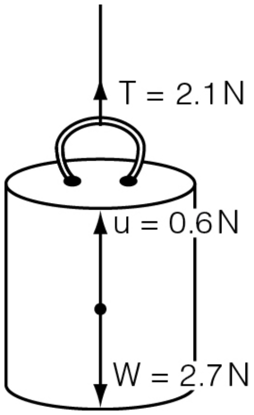
9.19 Newton's Third Law

a) The forces on the water and beaker are: their weight 6.8 N; a push down from the suspended weight of 0.6 N; a normal force of 7.4 N from the beaker.





b) The forces on the weight when it is in the water are: 2.1 N from the forcemeter; a weight of 2.7 N; an upthrust from the water of 0.6 N.

9.19 b) As the top magnet is lowered, the force of attraction between the magnets increases. This force acts downwards on the suspended magnet and so the force on the forcemeter, initially equal to the weight of a single magnet, increases.

The force acts upwards on the magnet resting on the balance and so the force on the balance, also initially equal to the weight of a single magnet, decreases.

When the magnets are close enough for the force between them to be fractionally more than the weight of a single magnet, the lower magnet will accelerate upwards, leaving the balance and stick to the upper one so the balance will read zero and the reading on the forcemeter will be equal to the weight of two magnets.

Pages 162–167 Practice questions

1 D

2 A

3 C

4 C

5 B

6 B

7 C

8 D

9 C

10 D

11 B

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12 a) Volume $= \pi r^2 h = \pi \times (0.06\ \text{m})^2 \times 0.15\ \text{m} = 0.0017\ \text{m}^3$ [1]

Mass = density × volume = 720 kg m^{-3} × 0.0017 m^3 = 1.22 kg [1]

Weight = m g = 1.22 kg × 9.8 N kg^{-1} = 12.0 N [1]

b) A body remains at rest or continues to move in a straight line at a constant speed unless acted on by an unbalanced force. [1]

c) *A*: contact force from X = 12 N [1]

B: weight of Y = 12 N [1]

C: contact force from table = 24 N [1]

d) i) 12 N [1]

ii) upwards [1]

iii) gravitational [1]

iv) the Earth [1]

13 a) Total weight = 580 N + 2 kg × 9.8 N kg^{-1} = 600 N (2 sig figs) [1]

b) i) She accelerates the weight upwards by applying a force. [1]
The weight pushes back on her with an equal and opposite force so the force on the scale increases. [1]

ii) She slows the weight down, so applies a downwards force on it. [1]
The weight pulls her up, so the force on the scales is less. [1]

iii) The weight is stationary above her head, the forces on it balance. [1]
So the scale reads the weight of the student (580 N) and the 2 kg mass (20 N). [1]

14 a) Treating the two boxes as a single object and using**:**

F = ma:

50 N – 5 N = 25 kg × a [1]

So, a = (45/25) m s^{-2} [1]

a = 1.8 m s^{-2} [1]

b) Considering the smaller box only:

T – 2 N = 10 kg × 1.8 m s^{-2} [1]

T = 20 N [1]

15 a) i) $F_{resultant}$ = ma = 2 × 48 kg × 1.2 m s^{-2} [1]

= 115 N [1]

ii) F_{res} = 250 N – 115 N = 135 N [1]

b) Resultant force on Q F_Q = ma = 48 kg × 1.2 m s^{-2} = 58 N [1]

but $F_Q = 250\ \text{N} - F_p - \frac{1}{2}F_{res}$ F_p is the force P exerts on Q [1]

$58\ \text{N} = 250\ \text{N} - F_p - \frac{135}{2}\ \text{N}$ [1]

$\Longrightarrow F_p \quad = 250\text{ N} - 67.5\text{ N} - 58\text{ N} \quad = 124.5\text{ N or } 125\text{ N to 3 sf}$ [1]

16 a) The high pressure creates a force that pushes water backwards out of the bottle. [1]
Newton's third law tells us that the water exerts an equal and opposite force on the bottle, (and hence the plane to which it is fixed). [1]
This forward force which acts on the plane is unbalanced. [1]
So Newton's second law tells us the place will accelerate forwards [1].

b) i) $a = \frac{v-u}{t} = \frac{2.8\, m\, s^{-1} - 2.0\, m\, s^{-1}}{1\, s}$ [1]

$= 0.8\text{ m s}^{-2}$ [1]

ii) $a = \frac{v-u}{t} = \frac{4.0\, m\, s^{-1} - 2.8\, m\, s^{-1}}{1\, s}$ [1]

$= 1.2\text{ m s}^{-2}$ [1]

(In an AS exam you will not be asked to do the same calculation twice – but this gives you practice.)

iii) The mass of the plane has decreased as water escaped [1]
$a = \frac{F}{m}$, so the acceleration increases. [1]

c) $F = m\,a = 1.3\text{ kg} \times 0.8\text{ m s}^{-2}$ [1]

$= 1.0\text{ N}$ [1]

d) At E. [1]
This is when the plane starts to decelerate, so the only force acting must be a drag force. [1]

e) i) The drag force is increasing with speed or/and the reduced pressure in the bottle means the force with which it expelled (and hence the force it creates on the plane) is less so the resultant force is less [1]
so, once this effect becomes more significant than the reduction in mass, the acceleration is less [2]

ii) The drag balances the forwards force of the water on the plane; speed is constant. [1]

iii) The drag force decelerates the plane. [1]
The drag force gets less as the plane slows, so the deceleration is reduced. [1]

iv) The plane hits the ground and stops abruptly. [1]

f) Distance travelled = area under graph. [1]

This is closest to 35 m [1]

There is no need to do a detailed calculation. Can see that the distance is less than $5.5\text{ ms}^{-1} \times 9.5\text{ s} = 52.25\text{ m}$ (i.e. if it had travelled at max speed for the entire flight) – so ruling out (iii) and (iv) – but more than $2\text{ ms}^{-1} \times 9.5\text{ s} = 19\text{ m}$ (i.e. if it had travelled at initial speed for the entire flight – small amount of time going more slowly more than compensated for my time going more quickly), so ruling out (i).

g) i) The energy is transferred from the air in the bottle [1]
where it was stored as (elastic) potential energy between molecules that were squashed closer together. [1]

ii) The water (and air) that is pushed from the bottle (and out of the way of the plane). [1]

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17 a) These gaps are likely to have been measured to the nearest millimetre (or half millimetre). As they stand, the error for the smaller measurements is large – perhaps 0.5 mm in 2 mm for the first interval, which corresponds to 25%. The error is *mu*ch smaller for the larger intervals (0.5 mm in 25 mm is a 2% error). [1]
It would be difficult to measure the distance between dots with greater precision, but alternative timing methods(see, f below) could provide greater accuracy.[1]

b) t = 3 × 0.02 s = 0.06 s [1]

v = 11.0 mm ÷ 0.02 s = 550 mms^{-1}; u = 2.0 mm ÷ 0.02 s = 100 mms^{-1} [1]

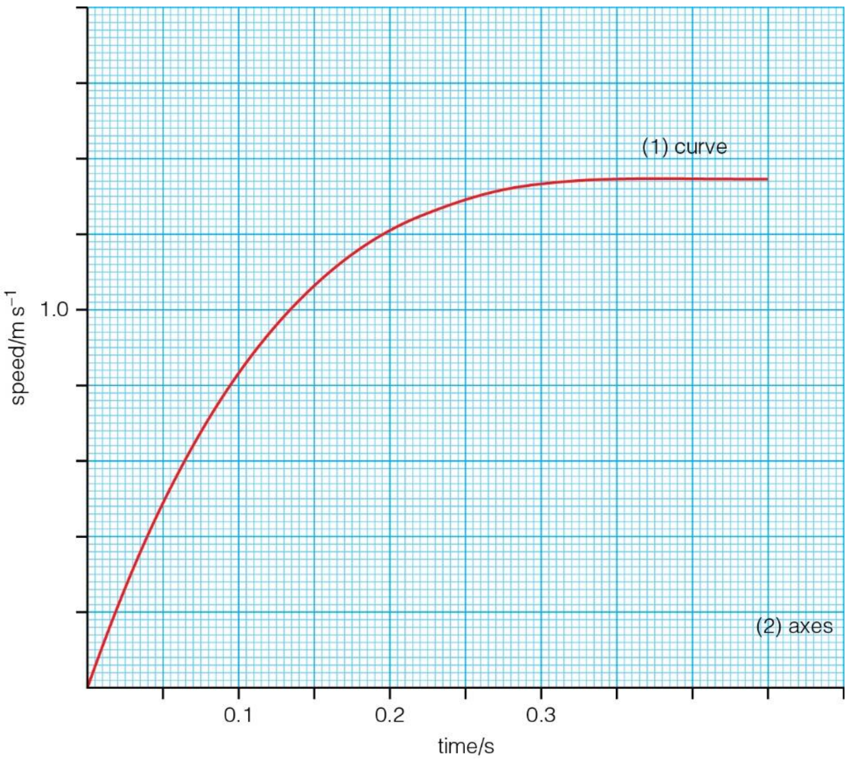
$a = \frac{v - u}{t} = \frac{500 - 100}{0.06}$ [1]

= 7500 mms^{-2} = 7.5 m s^{-2} [1]

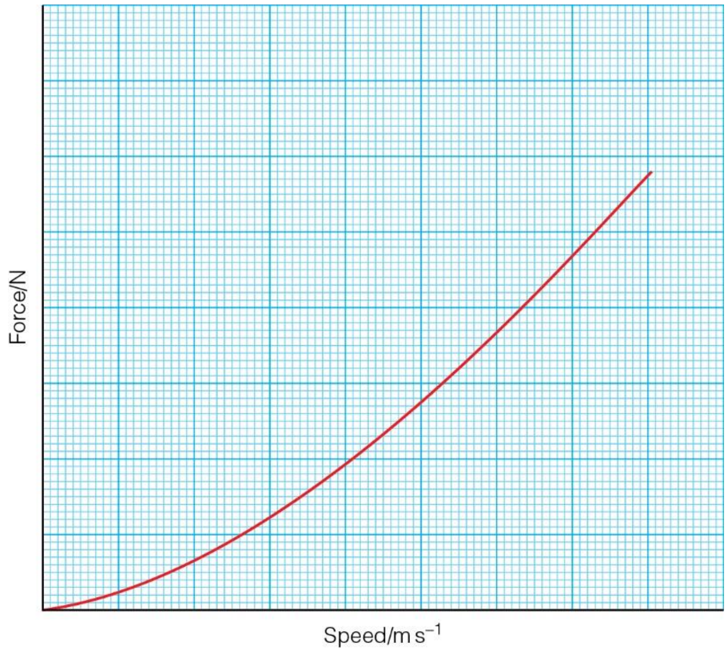
c) The gaps increased by 3 mm per interval at the start, and are roughly constant at the end. [1]
Therefore, the rate at which the speed increases gets less; i.e. the acceleration decreases. [1]

d) Using the average separation between dots over the last four intervals: [1]
Terminal speed = $\frac{25.5\ mm}{0.02\ s}$ = 1.275 mms^{-1} = 1.3 m s^{-1} [1]

e) i) One mark for increasing speed up to around 0.3 s;
One mark for showing a constant speed consistent with (d) at the end.



ii) Two marks for showing increasing drag with speed (there is insufficient data to be sure of the relationship, so form of curve/line irrelevant).



f) Any four relevant points e.g.
the water exerts an upthrust on the weight, which has not been considered
the tape exerts a drag force (and will itself experience an upthrust)
once the tape is wet it may stretch (or it may tear on removal)
friction in the timer will also affect measurements
A better method could be devised using light gates, as they do not interfere with the motion of the mass. [4]

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Page 167 Stretch and challenge

18 a) To every force there is an equal and opposite force. So each fragment going one way must be balanced by a fragment going in the opposite direction.

However, this is a simplification. One fragment could be balanced by two or more fragments going in the opposite direction. (You could also think of the conservation of momentum.)

b) For P and R, the initial vertical velocity is 0.

So:

$s = \frac{1}{2} g\, t^2$

$t^2 = \frac{2s}{g}$

$= \frac{2 \times 100 \text{ m}}{9.8 \text{ ms}^{-1}}$

$t = 4.5$ s

For the next calculations you need to remember the solution to a quadratic equation.

$ax^2 + bx + c = 0$

$x = \frac{-b \pm .(b^2 - 4ac)^{\frac{1}{2}}}{2a}$

Taking down as positive, for Q:

$s = ut + \frac{1}{2} gt^2$

$100 = -30\, t + 4.9\, t^2$

$\Longrightarrow 4.9\, t^2 - 30\, t - 100 = 0$

$t = \frac{30 \pm (900 + 4 \times 4.9 \times 100)^{\frac{1}{2}}}{2 \times 4.9}$

$t = \frac{30 \pm 53.5 \text{ s}}{9.8}$

$t = 8.5$ s (This is the only valid solution as we cannot have negative time.)

For S:

$s = u\, t + \frac{1}{2} g\, t^2$

$100 = 30\, t + 4.9\, t^2$

$\Longrightarrow 4.9\, t^2 + 30\, t - 100 = 0$

$T = \frac{-30 \pm (900 + 4 \times 4.9 \times 100)^{\frac{1}{2}}}{9.8}$

$= \frac{-30 \pm 53.5 \text{ s}}{9.8}$

$= 2.4$ s (As before, this is the only valid solution.)

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c) Q and S land below the centre of gravity. For P and R the horizontal distance travelled is:

$s = 30\ \text{m s}^{-1} \times 4.5\ \text{s}$

$= 135\ \text{m}$

R: 135 m to the right; P: 135 m to the left.

d) Final kinetic energy = initial kinetic energy + GPE transferred.

$KE = \frac{1}{2} m v^2 + m g h$

$= \frac{1}{2} \times 0.1 \times 30^2 + 0.1 \times 9.8 \times 100$

$= 45\ \text{J} + 98\ \text{J}$

$= 143\ \text{J}$ or $140\ \text{J}$ (2 sig figs)

This is the same for all fragments as energy is a scalar.

e) Again, all fragments have a kinetic energy of 140 J on landing.

19 a) $W_1 = mg = 80\text{kg} \times 10\text{N/kg} = 784\ \text{N}$

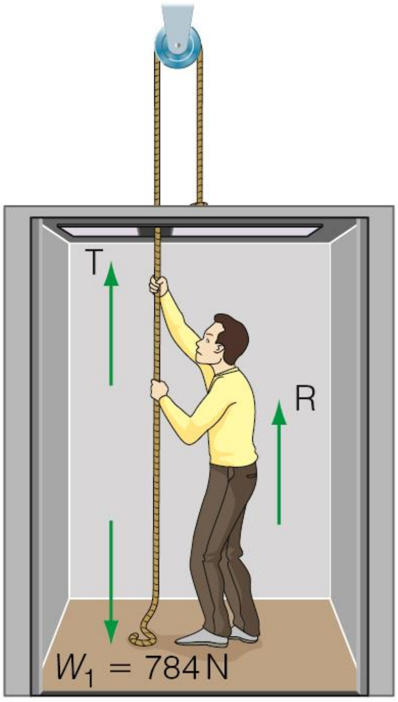
$W_2 = 40\text{kg} \times 10\text{N/kg} = 392\ \text{N}$

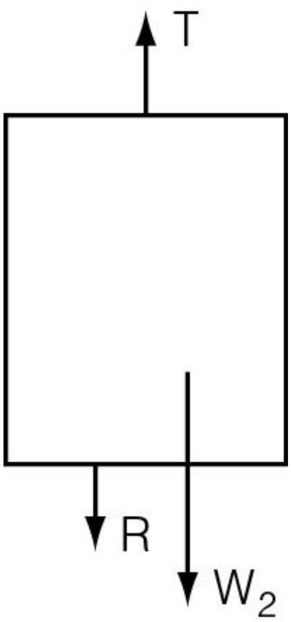
For the man: $T + R = 784\ \text{N}$
For the lift: $T - R = 392\ \text{N}$

Adding these equations gives $2T = 1176\ \text{N}$
(which could also be determined by considering the system as a whole: $2T = W_1 + W_2$)

$\Rightarrow T = 588\ \text{N}$

$\Rightarrow R = 784\ \text{N} - 588\ \text{N} = 196\ \text{N}$





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b) Resultant force = ma = 2 T – W_1 – W_2 = (m_1 + m_2) a

(2 × 648) N – 784 N – 392 N = (40 + 80) kg × a

120 N = 120 kg × a

a = 1.0 m s^{-2}

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