

Exercise walk-through

3.1.1

Resultant force, $F = ma$, weight and third-law pairs

A-Level Physics

3.1.1 Resultant force, $F = ma$, weight and third-law pairs

Name: _____ Class: _____ Date: _____ **Total: 35 marks**

KEY WORDS resultant force • normal contact force • tension • mass
• weight

Objective

Answer exam questions that use **Newton's laws of motion** when several forces act on one object: finding the **resultant force** and using $F = ma$, weight, the forces in a lift and between joined objects, and **third-law pairs**.
Syllabus 3.1, learning outcomes 2, 5 and 6.

You must be able to:

- use weight $F_W = mg$, and explain how **mass** and **weight** differ
- draw the forces on **one** object, add them with signs, and use $F = ma$ with the acceleration in the direction of the resultant force
- find the **normal contact force** on a person in a lift that is speeding up or slowing down

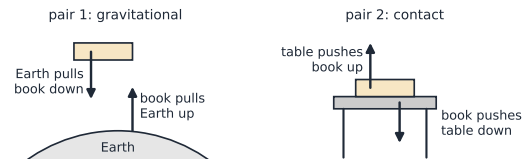
- find the acceleration of two joined objects, then the force between them
- name the other force of a Newton's third-law pair

1 Key knowledge and worked examples

■ Key knowledge: mass, weight and resultant force

- **Mass** is resistance to acceleration: scalar, kg, unchanged on another planet.
- **Weight** is gravitational force: $F_W = mg$, vector, N, towards the attracting body.
For 2.0 kg: Earth $F_W = mg = 2.0 \times 9.81 = 19.6$ N; Mars $F_W = mg = 2.0 \times 3.7 = 7.4$ N.
- Draw only forces **on** the chosen object; resolve angled forces; choose a positive direction; add force components with signs. $F_{\text{res}} = ma$ acts in the acceleration direction, which can oppose velocity.
- At rest/constant velocity, $F_{\text{res}} = 0$. For driving force F_{drive} and resistance F_R , $a = (F_{\text{drive}} - F_R)/m$: $F_{\text{drive}} > F_R$ speeds up; $F_{\text{drive}} < F_R$ slows forward motion.

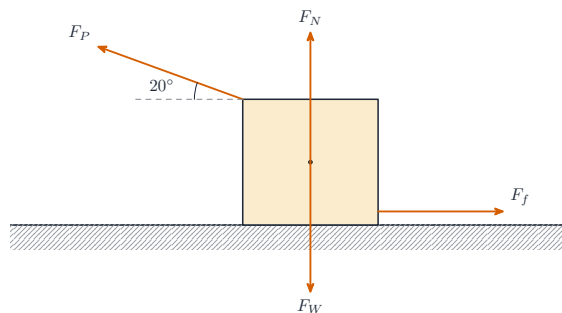
■ Newton's third-law pairs



If A exerts a force on B, B exerts an equal, opposite force of the same type on A. **Swap the object names** to find the partner. The pair acts on different objects; it cannot cancel on one object's force diagram. Weight and normal force on the book are not a pair.

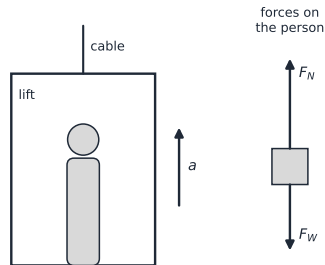
■ Worked example: angled pull

A 6.0 kg box is pulled left by 40 N at 20° above horizontal, against 15 N friction.



- Leftward component $F_{P,x} = F_P \cos \theta = 40 \cos 20^\circ = 37.6$ N; upward component $F_{P,y} = F_P \sin \theta = 40 \sin 20^\circ = 13.7$ N.
- Along motion: $F_{\text{res}} = F_{P,x} - F_f = 37.6 - 15 = 22.6$ N, hence $a = F_{\text{res}}/m = 22.6/6.0 = 3.8 \text{ m s}^{-2}$ left.
- Vertically: $F_N + F_{P,y} = F_W$. Therefore $F_N = mg - F_{P,y} = 6.0 \times 9.81 - 13.7 = 45$ N.

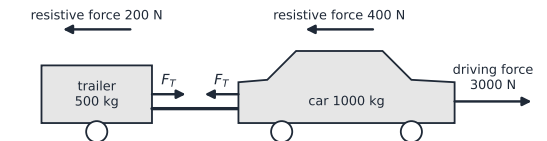
■ Worked example: a person in a lift



Up positive: $F_N - F_W = ma$, so $F_N = m(g + a)$. Scales read F_N , not F_W .

Lift acceleration	Scale reading
up, 1.5 m/s^2	$F_N = m(g + a) = 60(9.81 + 1.5) = 680 \text{ N}$
zero, either velocity direction	$F_N = mg = 60 \times 9.81 = 589 \text{ N}$
down, 1.5 m/s^2	$F_N = m(g + a) = 60(9.81 - 1.5) = 500 \text{ N}$

■ Worked example: car and trailer



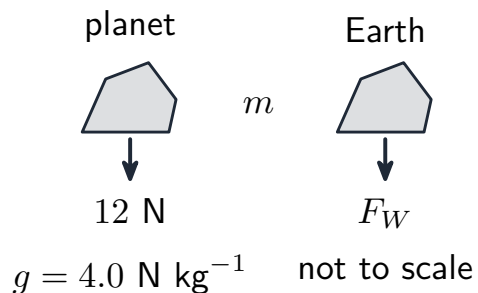
- Whole system: internal tension cancels. $a = (F_{\text{drive}} - F_{R,c} - F_{R,t}) / (m_c + m_t) = (3000 - 400 - 200) / (1000 + 500) = 1.6 \text{ m s}^{-2}$.
- Trailer alone: $F_T - F_{R,t} = m_t a$. Thus $F_T = m_t a + F_{R,t} = 500 \times 1.6 + 200 = 1000 \text{ N}$.
- Car check: $F_c = F_{\text{drive}} - F_{R,c} - F_T = 3000 - 400 - 1000 = 1600 \text{ N}$; $m_c a = 1000 \times 1.6 = 1600 \text{ N}$.
- For a table block and hanging mass, choose positive directions along the string: $F_T = m_1 a$ and $m_2 g - F_T = m_2 a$. A light string/smooth pulley gives equal tensions; a taut inextensible string gives equal acceleration magnitudes.

Exercise 2.1 (a)

2.1 A rock sample has a weight of 12 N on a planet where $g = 4.0 \text{ N kg}^{-1}$.

(a) Calculate the mass of the rock.

[1]

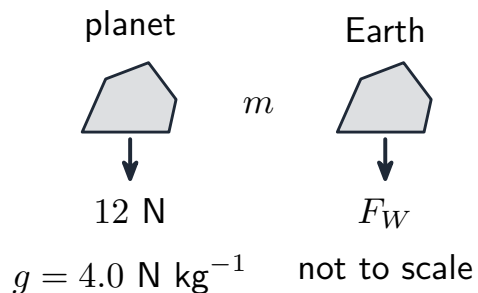


Exercise 2.1 (a)

2.1 A rock sample has a weight of 12 N on a planet where $g = 4.0 \text{ N kg}^{-1}$.

(a) Calculate the mass of the rock.

[1]



(a) from $F_W = mg$: $m = F_W/g = 12 \text{ N}/4.0 \text{ N kg}^{-1} = \mathbf{3.0 \text{ kg}}$

Exercise 2.1 (b)

2.1 A rock sample has a weight of 12 N on a planet where $g = 4.0 \text{ N kg}^{-1}$.

(b) Calculate the weight of the rock on the Earth.

[1]

Exercise 2.1 (b)

2.1 A rock sample has a weight of 12 N on a planet where $g = 4.0 \text{ N kg}^{-1}$.

(b) Calculate the weight of the rock on the Earth.

[1]

(b) the mass does not change, so $F_W = mg = 3.0 \text{ kg} \times 9.81 \text{ N kg}^{-1} = \mathbf{29 \text{ N}}$

Exercise 2.2 (a)

2.2 A sledge of mass 12 kg is pulled across flat snow by a rope at 25° above the horizontal. The tension in the rope is 50 N, and the friction force on the sledge is 20 N.

(a) Calculate the horizontal component of the tension.

[1]

Exercise 2.2 (a)

2.2 A sledge of mass 12 kg is pulled across flat snow by a rope at 25° above the horizontal. The tension in the rope is 50 N, and the friction force on the sledge is 20 N.

(a) Calculate the horizontal component of the tension. [1]

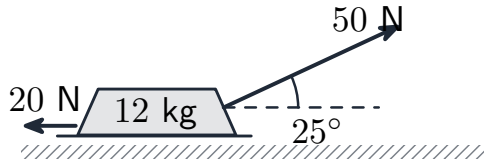
(a) $F_{T,H} = F_T \cos \theta = 50 \text{ N} \times \cos 25^\circ = \mathbf{45 \text{ N}}$

Exercise 2.2 (b)

2.2 A sledge of mass 12 kg is pulled across flat snow by a rope at 25° above the horizontal. The tension in the rope is 50 N, and the friction force on the sledge is 20 N.

(b) Calculate the acceleration of the sledge.

[2]

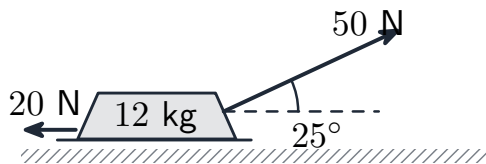


Exercise 2.2 (b)

2.2 A sledge of mass 12 kg is pulled across flat snow by a rope at 25° above the horizontal. The tension in the rope is 50 N, and the friction force on the sledge is 20 N.

(b) Calculate the acceleration of the sledge.

[2]



(b) resultant force along the snow: $F_{\text{res}} = F_T \cos \theta - F_f = 45.3 - 20 = 25.3 \text{ N}$

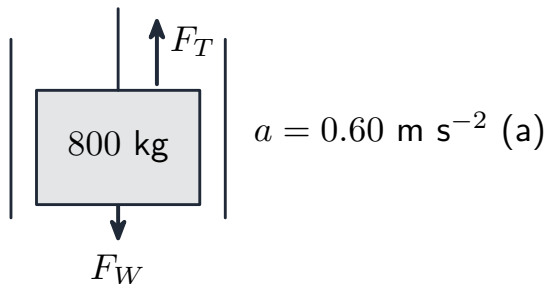
- Newton's second law $F_{\text{res}} = ma$: $a = \frac{F_{\text{res}}}{m} = \frac{25.3 \text{ N}}{12 \text{ kg}} = \mathbf{2.1 \text{ m s}^{-2}}$

Exercise 2.3 (a)

2.3 A lift and its passengers have a total mass of 800 kg. The lift is pulled up by a cable. Calculate the tension in the cable when the lift is:

(a) accelerating upwards at 0.60 m s^{-2}

[2]

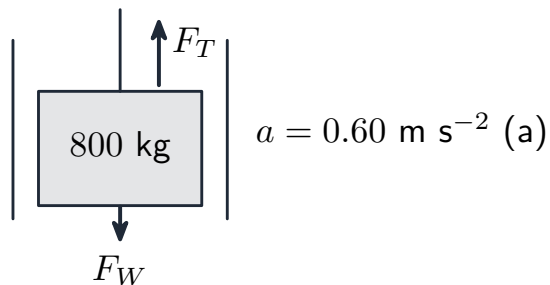


Exercise 2.3 (a)

2.3 A lift and its passengers have a total mass of 800 kg. The lift is pulled up by a cable. Calculate the tension in the cable when the lift is:

(a) accelerating upwards at 0.60 m s^{-2}

[2]



(a) up positive, $F_{\text{res}} = ma$ with $F_{\text{res}} = F_T - mg$

$$F_T = m(g + a) = 800 \text{ kg} \times (9.81 + 0.60) \text{ m s}^{-2} = \mathbf{8330 \text{ N}}$$

Exercise 2.3 (b)

2.3 A lift and its passengers have a total mass of 800 kg. The lift is pulled up by a cable. Calculate the tension in the cable when the lift is:

(b) moving upwards at a constant speed.

[1]

Exercise 2.3 (b)

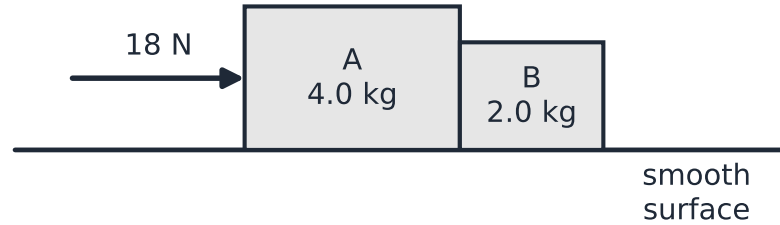
2.3 A lift and its passengers have a total mass of 800 kg. The lift is pulled up by a cable. Calculate the tension in the cable when the lift is:

(b) moving upwards at a constant speed. [1]

(b) constant speed, so the resultant force is zero (first law): $F_T = mg = 800 \times 9.81 =$
7850 N

Exercise 2.4 (a)

2.4 Two blocks, A and B, are pushed along a smooth horizontal surface by a force of 18 N, as shown.

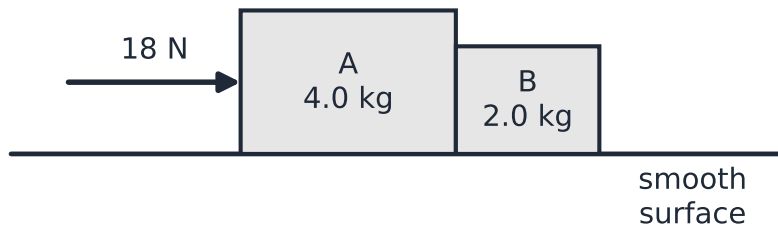


(a) Calculate the acceleration of the blocks.

[1]

Exercise 2.4 (a)

2.4 Two blocks, A and B, are pushed along a smooth horizontal surface by a force of 18 N, as shown.



(a) Calculate the acceleration of the blocks.

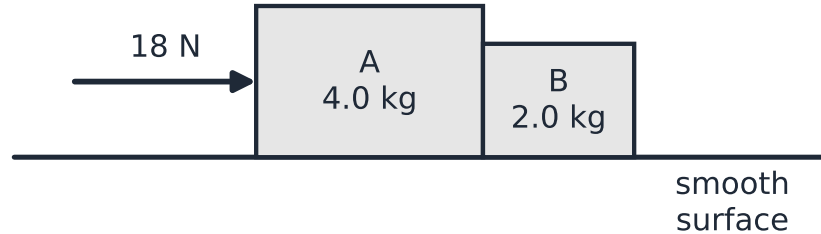
[1]

(a) both blocks as one object, $F_{\text{res}} = ma$ rearranged for a :

$$a = \frac{F}{m_A + m_B} = \frac{18 \text{ N}}{(4.0 + 2.0) \text{ kg}} = \mathbf{3.0 \text{ m s}^{-2}}$$

Exercise 2.4 (b)

2.4 Two blocks, A and B, are pushed along a smooth horizontal surface by a force of 18 N, as shown.

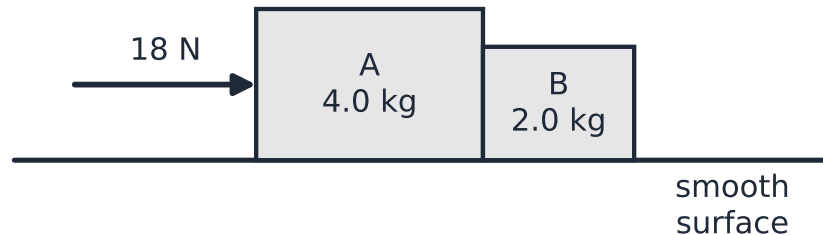


(b) Calculate the force that block A exerts on block B.

[2]

Exercise 2.4 (b)

2.4 Two blocks, A and B, are pushed along a smooth horizontal surface by a force of 18 N, as shown.



(b) Calculate the force that block A exerts on block B. [2]

(b) the only horizontal force on B is the push of A, so from $F = ma$ for B alone:
 $F = m_B a = 2.0 \text{ kg} \times 3.0 \text{ m s}^{-2} = \mathbf{6.0 \text{ N}}$

Exercise 3.1

3.1 A lift is moving upwards and slowing down. F_T is the tension in the cable and F_W is the weight of the lift. Which statement is correct? [1]

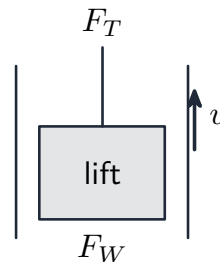
☐

A F_T is greater than F_W .

B F_T is equal to F_W .

C F_T is less than F_W .

D F_T is zero.



Exercise 3.1

3.1 A lift is moving upwards and slowing down. F_T is the tension in the cable and F_W is the weight of the lift. Which statement is correct? [1]

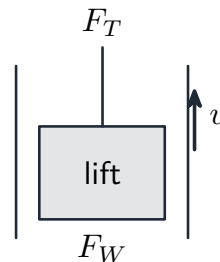
☐

A F_T is greater than F_W .

B F_T is equal to F_W .

C F_T is less than F_W .

D F_T is zero.



3.1 C

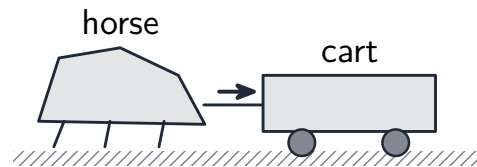
- the lift slows down while it moves up, so its acceleration and the resultant force are **downwards**: $F_W > F_T$
- A** is a lift speeding up on the way up, **B** a lift at constant velocity, and **D** a lift in free fall

Exercise 3.2

3.2 A horse pulls a cart forwards along a level road. Which force forms a Newton's third-law pair with the force of the horse on the cart? [1]

☐

- A** the force of the road on the cart
- B** the force of the cart on the horse
- C** the weight of the cart
- D** the force of the road on the horse

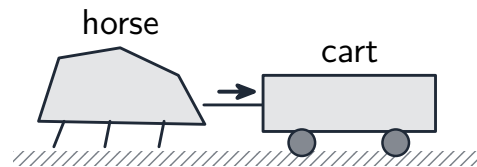


Exercise 3.2

3.2 A horse pulls a cart forwards along a level road. Which force forms a Newton's third-law pair with the force of the horse on the cart? [1]

☐

- A** the force of the road on the cart
- B** the force of the cart on the horse
- C** the weight of the cart
- D** the force of the road on the horse



3.2 B

- swap the two objects: the horse pulls the cart, so the partner is the cart pulling the horse
- **A**, **C** and **D** involve other objects or other types of force

Exercise 3.3 (a)

3.3 A car of mass 1100 kg tows a caravan of mass 900 kg along a straight, level road. The driving force on the car is 2600 N. The resistive force is 350 N on the car and 450 N on the caravan.

(a) State Newton's second law of motion.

[1]

Exercise 3.3 (a)

3.3 A car of mass 1100 kg tows a caravan of mass 900 kg along a straight, level road. The driving force on the car is 2600 N. The resistive force is 350 N on the car and 450 N on the caravan.

(a) State Newton's second law of motion.

[1]

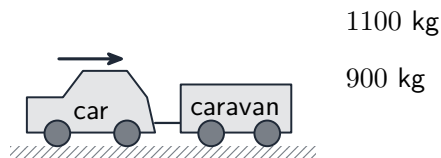
(a) the resultant force on an object is equal to its **rate of change of momentum**

Exercise 3.3 (b)

3.3 A car of mass 1100 kg tows a caravan of mass 900 kg along a straight, level road. The driving force on the car is 2600 N. The resistive force is 350 N on the car and 450 N on the caravan.

(b) Calculate the acceleration of the car and caravan.

[2]

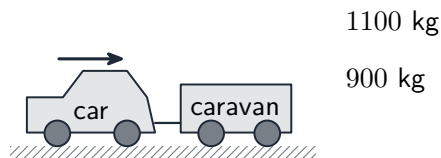


Exercise 3.3 (b)

3.3 A car of mass 1100 kg tows a caravan of mass 900 kg along a straight, level road. The driving force on the car is 2600 N. The resistive force is 350 N on the car and 450 N on the caravan.

(b) Calculate the acceleration of the car and caravan.

[2]



(b) car and caravan as one object: the resultant force is the driving force minus both resistive forces

$$F_{\text{res}} = F_{\text{drive}} - (F_{\text{car}} + F_{\text{caravan}}) = 2600 - (350 + 450) = 1800 \text{ N}$$

- $F_{\text{res}} = ma$, rearranged for a with $m = 1100 + 900 = 2000 \text{ kg}$

$$a = \frac{F_{\text{res}}}{m} = \frac{1800 \text{ N}}{2000 \text{ kg}} = \mathbf{0.90 \text{ m s}^{-2}}$$

Exercise 3.3 (c)

3.3 A car of mass 1100 kg tows a caravan of mass 900 kg along a straight, level road. The driving force on the car is 2600 N. The resistive force is 350 N on the car and 450 N on the caravan.

(c) **Show that** the force of the tow bar on the caravan is about 1300 N. [2]

Exercise 3.3 (c)

3.3 A car of mass 1100 kg tows a caravan of mass 900 kg along a straight, level road. The driving force on the car is 2600 N. The resistive force is 350 N on the car and 450 N on the caravan.

(c) **Show that** the force of the tow bar on the caravan is about 1300 N. [2]

(c) caravan on its own: F_T forwards and 450 N backwards, so $F_{\text{res}} = ma$ gives $F_T - F_{\text{caravan}} = m_{\text{caravan}}a$

$$F_T = m_{\text{caravan}}a + F_{\text{caravan}} = 900 \times 0.90 + 450 = \mathbf{1260} \text{ N} \approx 1300 \text{ N}$$

Exercise 3.3 (d)

3.3 A car of mass 1100 kg tows a caravan of mass 900 kg along a straight, level road. The driving force on the car is 2600 N. The resistive force is 350 N on the car and 450 N on the caravan.

(d) State the size and the direction of the force of the caravan on the tow bar, and name the law you used. [2]

Exercise 3.3 (d)

3.3 A car of mass 1100 kg tows a caravan of mass 900 kg along a straight, level road. The driving force on the car is 2600 N. The resistive force is 350 N on the car and 450 N on the caravan.

(d) State the size and the direction of the force of the caravan on the tow bar, and name the law you used. [2]

(d) 1260 N **backwards**

- Newton's **third** law

Exercise 3.3 (e)

3.3 A car of mass 1100 kg tows a caravan of mass 900 kg along a straight, level road. The driving force on the car is 2600 N. The resistive force is 350 N on the car and 450 N on the caravan.

(e) Later the car and caravan move at a constant speed, with the same resistive forces. State the driving force. [1]

Exercise 3.3 (e)

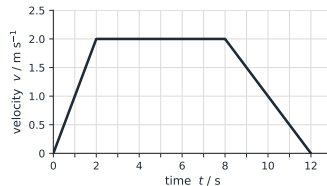
3.3 A car of mass 1100 kg tows a caravan of mass 900 kg along a straight, level road. The driving force on the car is 2600 N. The resistive force is 350 N on the car and 450 N on the caravan.

(e) Later the car and caravan move at a constant speed, with the same resistive forces. State the driving force. [1]

(e) the resultant force is zero, so the driving force balances both resistive forces: $F_{\text{drive}} = F_{\text{car}} + F_{\text{caravan}} = 350 + 450 = \mathbf{800 \text{ N}}$

Exercise 3.4

3.4 A student of mass 55 kg stands on bathroom scales in a lift. The graph shows how the velocity of the lift changes as it moves upwards from rest.



(a) **Determine** the acceleration of the lift between $t = 0$ and $t = 2.0$ s. [1]

(b) Calculate the reading of the scales, in newtons:

(i) between $t = 0$ and $t = 2.0$ s [2]

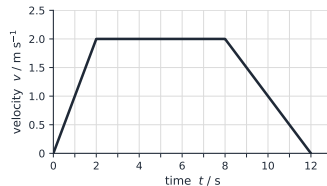
(ii) between $t = 2.0$ s and $t = 8.0$ s [1]

(iii) between $t = 8.0$ s and $t = 12.0$ s. [2]

(c) **Explain**, using Newton's laws, why the reading between $t = 8.0$ s and $t = 12.0$ s is less than the weight of the student. [2]

Exercise 3.4

3.4 A student of mass 55 kg stands on bathroom scales in a lift. The graph shows how the velocity of the lift changes as it moves upwards from rest.



(a) **Determine** the acceleration of the lift between $t = 0$ and $t = 2.0$ s. [1]

(b) Calculate the reading of the scales, in newtons:

(i) between $t = 0$ and $t = 2.0$ s [2]

(ii) between $t = 2.0$ s and $t = 8.0$ s [1]

(iii) between $t = 8.0$ s and $t = 12.0$ s. [2]

(c) **Explain**, using Newton's laws, why the reading between $t = 8.0$ s and $t = 12.0$ s is less than the weight of the student. [2]

3.4

(a) gradient of the graph: $a = \frac{\Delta v}{\Delta t} = \frac{2.0 \frac{\text{m}}{\text{s}}}{2.0 \text{ s}} = 1.0 \text{ m s}^{-2}$

(b)(i) up positive, $F_{\text{res}} = ma$ with $F_{\text{res}} = F_N - mg$

$$F_N = m(g + a) = 55 \text{ kg} \times (9.81 + 1.0) \text{ m s}^{-2} = 595 \text{ N}$$

Full solution on next slide

Full solution 3.4

3.4

(a) gradient of the graph: $a = \frac{\Delta v}{\Delta t} = \frac{2.0 \frac{\text{m}}{\text{s}}}{2.0 \text{ s}} = \mathbf{1.0 \text{ m s}^{-2}}$

(b)(i) up positive, $F_{\text{res}} = ma$ with $F_{\text{res}} = F_N - mg$

$$F_N = m(g + a) = 55 \text{ kg} \times (9.81 + 1.0) \text{ m s}^{-2} = \mathbf{595 \text{ N}}$$

(ii) constant velocity, so $F_N = mg = 55 \text{ kg} \times 9.81 \text{ m s}^{-2} = \mathbf{540 \text{ N}}$

(iii) $a = \frac{\Delta v}{\Delta t} = \frac{0 - 2.0 \frac{\text{m}}{\text{s}}}{4.0 \text{ s}} = -0.50 \text{ m s}^{-2}$

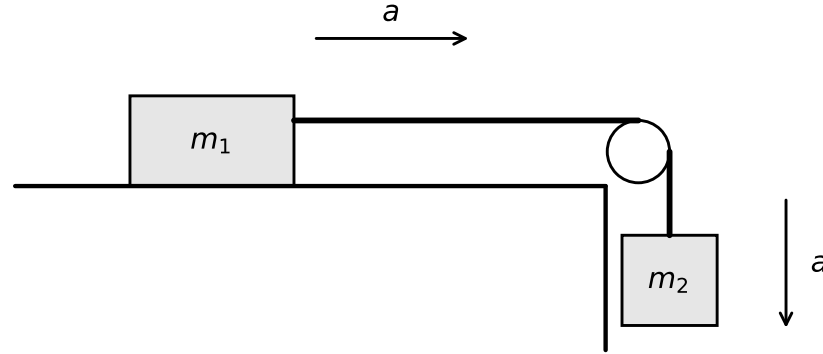
$$F_N = m(g + a) = 55 \text{ kg} \times (9.81 - 0.50) \text{ m s}^{-2} = \mathbf{512 \text{ N}}$$

(c) the lift slows down while it moves up, so the student's acceleration is **downwards**

- by the second law the resultant force on the student is downwards, so $F_W > F_N$ and the scales read less than the weight

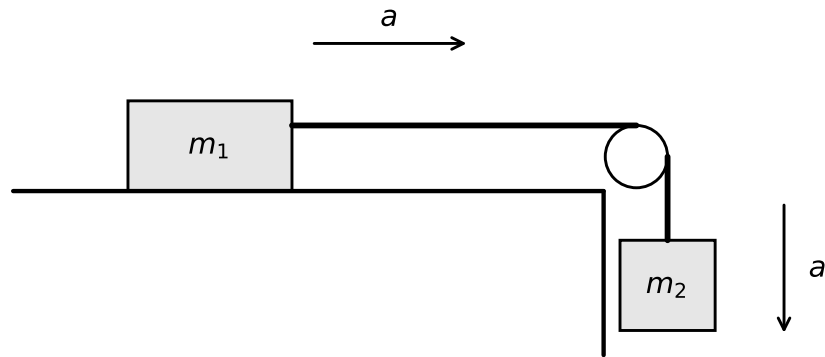
Exercise 3.5

3.5 A 3.0 kg block on a smooth horizontal table is connected to a hanging 2.0 kg mass by a light string over a smooth pulley. Take $g = 9.81 \text{ m s}^{-2}$. Draw a force diagram for each body, then calculate their acceleration and the tension. [6]



Exercise 3.5

3.5 A 3.0 kg block on a smooth horizontal table is connected to a hanging 2.0 kg mass by a light string over a smooth pulley. Take $g = 9.81 \text{ m s}^{-2}$. Draw a force diagram for each body, then calculate their acceleration and the tension. [6]



3.5

- Table block: weight down, normal force up and tension towards the pulley. Hanging

Full solution on next slide

Full solution 3.5

3.5

- Table block: weight down, normal force up and tension towards the pulley. Hanging mass: weight down and tension up.
- A taut inextensible string gives the same acceleration magnitude; a light string and smooth pulley give the same tension.
- Along the table, resultant force $F = ma$: $F_T = m_1a$.
- Downwards for the hanging mass: $m_2g - F_T = m_2a$.
- $a = m_2g/(m_1 + m_2) = 2.0 \times 9.81/(3.0 + 2.0) = 3.92 \text{ m s}^{-2}$.
- $F_T = m_1a = 3.0 \times 3.92 = 11.8 \text{ N}$.