

Forces step by step

Name: _____ Class: _____ Date: _____

Total: 71 marks

KEY WORDS resultant force • weight • normal contact force

1 Key knowledge and worked examples

On Earth, use $g = 9.81 \text{ m s}^{-2}$. For constant mass: $F_{\text{res}} = ma$; weight: $F_W = mg$. Constant velocity means zero resultant force.

2 Practice

2.1 A 20 kg delivery robot moves right on a level floor. Its driving force F_{drive} is 60 N right; resistance F_f is 20 N left.

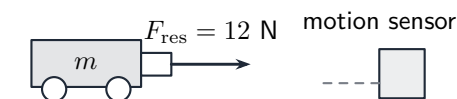
(a) Choose right positive. Find the **resultant force** using $F_{\text{res}} = F_{\text{drive}} - F_f$, then find $a = F_{\text{res}}/m$. [2]



(b) The motor switches off while the robot still moves right. Resistance stays 20 N. Find the new acceleration and state how the speed changes. [2]

2.2 A student uses a horizontal force sensor and a motion sensor to measure the mass of a cart. The measured resultant force is 12 N and its acceleration is 3.0 m s^{-2} .

(a) Rearrange $F_{\text{res}} = ma$ to calculate the cart's mass. [2]



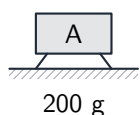
(b) A load is added. The same resultant force now produces an acceleration of 1.5 m s^{-2} . Calculate the mass of the added load. [2]

2.3 Two probes rest on different moons. Probe A has mass 200 g and weight 0.60 N. Probe B has mass 0.50 kg and weight 800 mN.

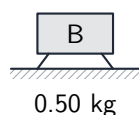
(a) Convert A's mass to kg and B's weight to N. [2]

(b) Use the weight equation to find g for each probe. Which moon has the weaker gravitational field? [2]

$$F_W = 0.60 \text{ N}$$



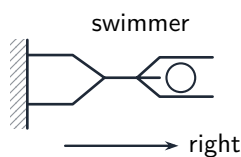
$$F_W = 800 \text{ mN}$$



(c) A student says: "B does not accelerate, so it has no weight." Explain the error. [1]

2.4 A swimmer pushes left on the wall of a pool with a force of 240 N. The wall is fixed to the ground.

(a) State the size and direction of the force of the wall on the swimmer. [2]

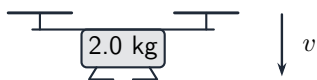


(b) A student says: "These equal and opposite forces cancel, so the swimmer cannot accelerate." Explain the error. [1]

(c) Which pairs with the swimmer's weight: the water's force on the swimmer or the swimmer's pull on Earth? State the object it acts on. [1]

2.5 A drone of mass 2.0 kg moves vertically downwards at constant speed. Its rotors exert an upward thrust F_{thrust} . Ignore air resistance.

- (a) Represent the drone by a dot. Draw and label its two forces during steady descent. Show their relative sizes with your arrows. [2]



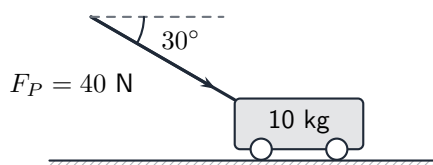
- (b) The thrust falls to 15.62 N. Choose a positive direction, write a force equation and calculate the acceleration, including its direction. [2]

- (c) Is the drone now speeding up or slowing down? Explain using the directions of velocity and acceleration. [1]

2.6 A cleaner pushes a 10 kg floor-cleaning machine with a 40 N force at 30° below horizontal. Resistance is 14.6 N. The machine stays on the floor.

- (a) Find the forward component using $F_{P,x} = F_P \cos 30^\circ$. [1]

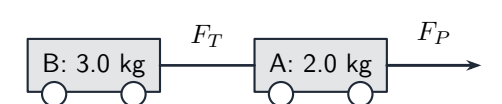
- (b) Find the downward component of the push. Write a vertical force equation and calculate the **normal contact force** from the floor. [2]



- (c) Write a horizontal force equation and calculate the machine's acceleration. [2]

2.7 Two carts are connected by a light, taut string. A motor pulls cart A right. Both accelerate at 1.2 m s^{-2} . Resistances are 0.6 N on A and 1.4 N on B.

(a) Draw and label all forces on B alone. Write its horizontal force equation and calculate the tension F_T . [3]

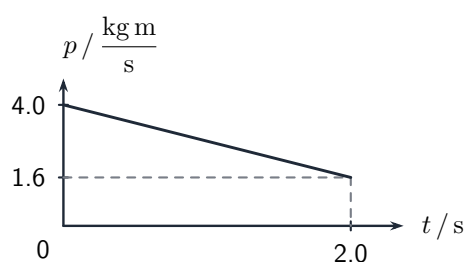


(b) Calculate the motor's pulling force F_P . Show which mass and forces you use. [2]

(c) Is $F_T = F_P$? Does the string pull B harder than B pulls the string? Explain both answers. [2]

2.8 A 0.80 kg glider moves right. A braking pad supplies the only horizontal force. Its **momentum** $p = mv$ changes as shown; right is positive.

(a) The gradient of a momentum-time graph gives the resultant force. Read the change in momentum and use $F_{\text{res}} = \Delta p / \Delta t$ to calculate this force, including its direction. [2]

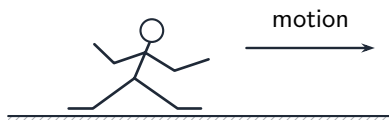


(b) Calculate the initial and final speeds from the graph. Hence calculate the distance travelled in the 2.0 s . [3]

3 Exam-style questions

Work independently. Show your force equations and give directions where needed.

3.1 A 60 kg runner moves along a level track. Her speed increases uniformly from 4.0 m s^{-1} to 8.0 m s^{-1} in 2.0 s. The average air resistance is 30 N.



(a) Calculate her acceleration, the average horizontal resultant force, and the average forward force of the ground on her. [3]

(b) State the size and direction of the force she exerts on the ground horizontally. Name the law used. [2]

(c) Sketch her velocity-time graph for these 2.0 s. Label both axes and the start and end values. [2]

(d) Calculate the distance she travels during these 2.0 s. [2]

3.2 A crane lowers a 200 kg beam on a vertical cable. The beam moves downwards at 1.2 m s^{-1} and slows uniformly to rest in 3.0 s. Ignore air resistance.



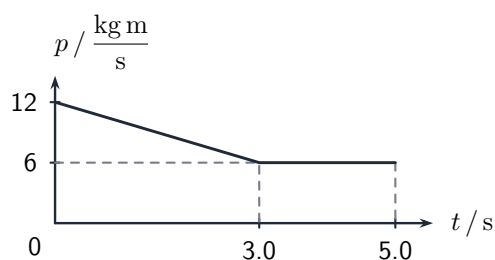
(a) Draw and label the forces on the beam. [2]

(b) Calculate the acceleration, giving its direction, and the cable tension during the slowing-down stage. [3]

(c) State the force of the beam on the cable, including direction. [1]

(d) The cable can sustain a maximum tension of 3000 N. Calculate the greatest mass it can raise with an upward acceleration of 0.40 m s^{-2} . [2]

3.3 A small powered vehicle moves right. Its momentum changes as shown. Resistance is constant at 3.0 N leftwards. The motor's driving force F_{drive} acts right.

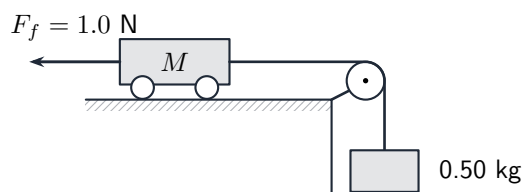


(a) State Newton's second law in terms of momentum. [1]

(b) Determine the resultant force, including direction, and the driving force at $t = 1.0$ s. [2]

(c) Sketch F_{drive} against time from 0 to 5.0 s. Label the force values and the time at which F_{drive} changes. [3]

3.4 A cart of unknown mass M is connected to a 0.50 kg hanging mass by a light, taut, inextensible string over a smooth pulley. The cart moves right against 1.0 N resistance. The measured acceleration is 1.50 m s^{-2} .



(a) Draw a labelled force diagram for each body. [2]

(b) Calculate the string tension. [2]

(c) Use the motion of the cart to determine M . [2]

(d) Replace the hanging mass with 0.80 kg . The cart and resistance are unchanged. Calculate the new acceleration. [3]

Solutions

Keep unrounded values for later steps. Small rounding differences are acceptable.

2.1

(a) Opposing forces subtract.

$$F_{\text{res}} = F_{\text{drive}} - F_f = 60 \text{ N} - 20 \text{ N} = 40 \text{ N}$$

$$a = \frac{F_{\text{res}}}{m} = \frac{40 \text{ N}}{20 \text{ kg}} = 2.0 \text{ m s}^{-2} \text{ right}$$

(b) The only horizontal force is now leftwards.

$$a = \frac{-F_f}{m} = \frac{-20 \text{ N}}{20 \text{ kg}} = -1.0 \text{ m s}^{-2}$$

Acceleration is leftwards, opposite the velocity, so the robot slows down.

2.2

(a) Mass measures resistance to acceleration.

$$m = \frac{F_{\text{res}}}{a} = \frac{12 \text{ N}}{3.0 \text{ m s}^{-2}} = 4.0 \text{ kg}$$

(b) First find the total mass, then subtract the empty cart.

$$m_{\text{total}} = \frac{F_{\text{res}}}{a} = \frac{12 \text{ N}}{1.5 \text{ m s}^{-2}} = 8.0 \text{ kg}$$

$$m_{\text{load}} = m_{\text{total}} - m = 8.0 \text{ kg} - 4.0 \text{ kg} = 4.0 \text{ kg}$$

2.3

(a) $200 \text{ g} = 0.200 \text{ kg}$; $800 \text{ mN} = 0.800 \text{ N}$.

(b) Compare weight per unit mass.

$$g_A = \frac{F_{W,A}}{m_A} = \frac{0.60 \text{ N}}{0.200 \text{ kg}} = 3.0 \text{ N kg}^{-1}$$

$$g_B = \frac{F_{W,B}}{m_B} = \frac{0.800 \text{ N}}{0.50 \text{ kg}} = 1.6 \text{ N kg}^{-1}$$

B's moon has the weaker field. B

(c) Zero acceleration means zero resultant force, not zero weight. The upward surface force balances the weight.

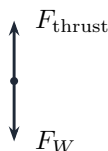
2.4

(a) 240 N to the right, by Newton's third law.

- (b) The forces act on different objects: one on the swimmer and one on the wall.
- (c) The swimmer's gravitational pull on Earth, acting on Earth. The water force acts on the swimmer and is a different interaction.

2.5

- (a) Force diagram : correct forces and directions; equal arrow lengths.



- (b) Choose down positive. Calculate weight, then subtract thrust to find the resultant.

$$F_W = mg = 2.0 \text{ kg} \times 9.81 \text{ m s}^{-2} = 19.62 \text{ N}$$

$$F_W - F_{\text{thrust}} = ma$$

$$a = \frac{mg - F_{\text{thrust}}}{m} = \frac{19.62 \text{ N} - 15.62 \text{ N}}{2.0 \text{ kg}} = 2.0 \text{ m s}^{-2} \text{ down}$$

- (c) It speeds up: velocity and acceleration both point downwards.

2.6

- (a) Resolve the push horizontally.

$$F_{P,x} = F_P \cos \theta = 40 \text{ N} \cos 30^\circ = 34.6 \text{ N}$$

- (b) The floor supports both the weight and the downward component.

$$F_N - F_W - F_{P,y} = 0$$

$$F_{P,y} = F_P \sin \theta = 40 \text{ N} \sin 30^\circ = 20.0 \text{ N}$$

$$F_N = mg + F_{P,y} = 10 \text{ kg} \times 9.81 \text{ m s}^{-2} + 20.0 \text{ N} = 118.1 \text{ N}$$

- (c) Subtract resistance from the horizontal component.

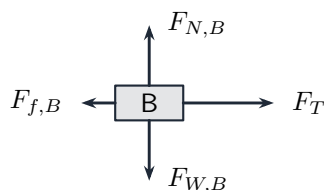
$$F_{P,x} - F_f = ma$$

$$F_{\text{res}} = F_P \cos \theta - F_f = 40 \text{ N} \cos 30^\circ - 14.6 \text{ N} = 20.0 \text{ N}$$

$$a = \frac{F_P \cos \theta - F_f}{m} = \frac{40 \text{ N} \cos 30^\circ - 14.6 \text{ N}}{10 \text{ kg}} = 2.00 \text{ m s}^{-2} \text{ forwards}$$

2.7

(a) Force diagram :



Tension must overcome B's resistance and accelerate B. B
B

$$F_T - F_{f,B} = m_B a$$

$$F_T = m_B a + F_{f,B} = 3.0 \text{ kg} \times 1.2 \text{ m s}^{-2} + 1.4 \text{ N} = 5.0 \text{ N}$$

(b) Use both masses; the string tension is internal.

$$F_P = (m_A + m_B)a + F_{f,A} + F_{f,B}$$

$$F_P = (2.0 + 3.0) \text{ kg} \times 1.2 \text{ m s}^{-2} + 2.0 \text{ N} = 8.0 \text{ N}$$

(c) No: $F_T = 5.0 \text{ N} < F_P = 8.0 \text{ N}$. The motor also accelerates A against resistance.
A

B and the string exert equal and opposite forces on each other, even during acceleration:
Newton's third law. B B ,

2.8

(a) Read the two endpoint momenta. The slope is negative, so the force is leftwards.

$$\Delta p = p_{\text{final}} - p_{\text{initial}} = (1.6 - 4.0) \text{ kg m s}^{-1} = -2.4 \text{ kg m s}^{-1}$$

$$F_{\text{res}} = \frac{\Delta p}{\Delta t} = \frac{-2.4 \text{ kg m s}^{-1}}{2.0 \text{ s}} = -1.2 \text{ N}$$

(b) Divide momentum by mass to find velocity.

$$u = \frac{p_{\text{initial}}}{m} = \frac{4.0 \text{ kg m s}^{-1}}{0.80 \text{ kg}} = 5.0 \text{ m s}^{-1}$$

$$v = \frac{p_{\text{final}}}{m} = \frac{1.6 \text{ kg m s}^{-1}}{0.80 \text{ kg}} = 2.0 \text{ m s}^{-1}$$

Constant mass and graph gradient mean constant acceleration. Use average velocity.

$$s = \frac{u + v}{2} t = \frac{(5.0 + 2.0) \text{ m s}^{-1}}{2} \times 2.0 \text{ s} = 7.0 \text{ m}$$

3.1

(a) Find acceleration from the change of velocity, then use the resultant force.

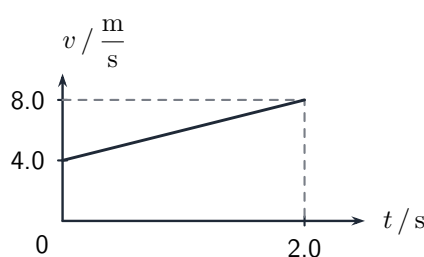
$$a = \frac{v - u}{\Delta t} = \frac{(8.0 - 4.0) \text{ m s}^{-1}}{2.0 \text{ s}} = 2.0 \text{ m s}^{-2}$$

$$F_{\text{res}} = ma = 60 \text{ kg} \times 2.0 \text{ m s}^{-2} = 120 \text{ N}$$

$$F_{\text{drive}} = ma + F_D = 120 \text{ N} + 30 \text{ N} = 150 \text{ N}$$

(b) 150 N backwards on the ground, by Newton's third law.

(c) Velocity-time graph :



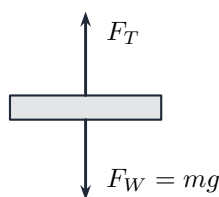
(d) Use average velocity because the acceleration is constant.

$$s = \frac{u + v}{2} t = \frac{(4.0 + 8.0) \text{ m s}^{-1}}{2} \times 2.0 \text{ s} = 12 \text{ m}$$

Equivalently use $s = ut + \frac{1}{2}at^2$.

3.2

(a) Upward tension and downward weight.



(b) Choose up positive. The initial velocity is negative, and becomes zero.

$$a = \frac{v - u}{\Delta t} = \frac{[0 - (-1.2)] \text{ m s}^{-1}}{3.0 \text{ s}} = 0.40 \text{ m s}^{-2} \text{ up}$$

$$F_T - mg = ma \quad \Rightarrow \quad F_T = m(g + a)$$

$$F_T = m(g + a) = 200 \text{ kg} \times (9.81 + 0.40) \text{ m s}^{-2} = 2042 \text{ N}$$

(c) 2042 N downwards on the cable. The third-law pair remains equal during acceleration.
2042 N

(d) Use the tension limit in the same force equation.

$$m_{\max} = \frac{F_{T,\max}}{g + a} = \frac{3000 \text{ N}}{(9.81 + 0.40) \text{ m s}^{-2}} = 294 \text{ kg}$$

3.3

(a) Resultant force equals the rate of change of momentum, in the direction of that change.

(b) Choose right positive. Use the negative gradient.

$$F_{\text{res}} = \frac{\Delta p}{\Delta t} = \frac{(6 - 12) \text{ kg m s}^{-1}}{3.0 \text{ s}} = -2.0 \text{ N}$$

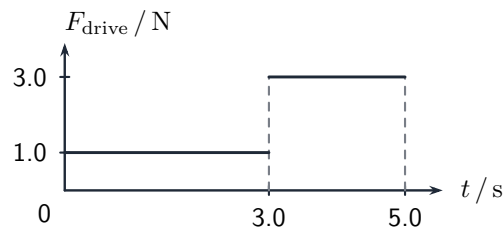
The resultant is 2.0 N leftwards.

$$F_{\text{drive}} - F_f = F_{\text{res}} \quad \Rightarrow \quad F_{\text{drive}} = F_f + F_{\text{res}}$$

$$F_{\text{drive}} = F_f + F_{\text{res}} = 3.0 \text{ N} + (-2.0 \text{ N}) = 1.0 \text{ N}$$

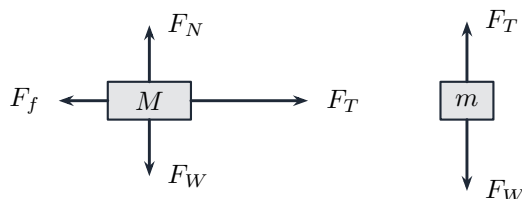
(c) Constant momentum means zero resultant force: driving force equals resistance.

$$F_{\text{drive}} = F_f = 3.0 \text{ N}$$



3.4

(a) Force diagrams :



(b) Start with the known hanging mass, choosing down positive.

$$mg - F_T = ma \quad \Rightarrow \quad F_T = m(g - a)$$

$$F_T = m(g - a) = 0.50 \text{ kg} \times (9.81 - 1.50) \text{ m s}^{-2} = 4.155 \text{ N}$$

(c) For the cart, tension minus resistance is the resultant.

$$F_T - F_f = Ma \quad \Rightarrow \quad M = \frac{F_T - F_f}{a}$$

$$M = \frac{F_T - F_f}{a} = \frac{4.155 \text{ N} - 1.0 \text{ N}}{1.50 \text{ m s}^{-2}} = 2.10 \text{ kg}$$

(d) Both the driving weight and total mass change. Add the two force equations to eliminate the new tension.

$$F'_T - F_f = Ma', \quad m'g - F'_T = m'a'$$

$$a' = \frac{m'g - F_f}{M + m'}$$

$$a' = \frac{m'g - F_f}{M + m'} = \frac{0.80 \text{ kg} \times 9.81 \text{ m s}^{-2} - 1.0 \text{ N}}{(2.10333 + 0.80) \text{ kg}} = 2.36 \text{ m s}^{-2}$$

The cart accelerates right and the hanging mass down.