

Exercise walk-through

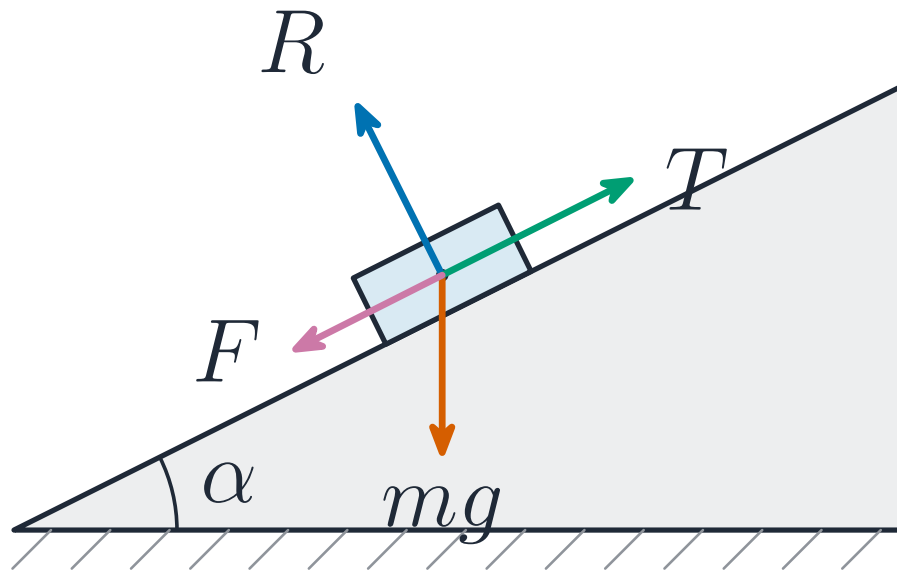
4.4

# Newton's laws of motion

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A-Level Mathematics

# Newton's laws



$$F = ma, \quad W = mg.$$

On an **inclined plane** :  
resolve along and perpendicular to  
the slope, then apply  $F = ma$ .

**Pull 12 kg up a  $20^\circ$  rough  
slope**

$$T \approx 110 \text{ N}$$

# The laws, and the forces they name

## Newton's laws of motion

**Newton's laws of motion** : a body keeps its velocity unless a **resultant** force acts;  $F = ma$ ; and every force has an equal and opposite partner.

## Newton's third law

**Newton's third law** pairs act on *different* bodies – which is why they never cancel in one free-body diagram.

## Connected particles

For **connected particles** write  $F = ma$  for each body separately, with the same acceleration and the tension appearing twice, in opposite directions.

## Thrust

A light rod can push as well as pull: the compression force is **thrust**, and a string can never provide it.

**Limiting equilibrium** is the instant before sliding: friction is at its maximum  $\mu R$ , and the body is still in equilibrium.

# Energy, work and power

$$W = Fd \cos \theta, \quad \text{KE} = \frac{1}{2}mv^2, \quad \text{PE} = mgh.$$

No friction  $\Rightarrow$  total energy conserved. Power  
 $P = Fv$ .

**12 kW engine at 20 m/s**

$$F = \frac{P}{v} = 600 \text{ N}$$

# The energy quantities you can calculate

kinetic energy

$$\frac{1}{2}mv^2$$

gravitational potential energy

 $mgh$ , measured from a stated level

work done

 $Fd$  – force times distance **along the force**

power

$$\frac{\text{work}}{\text{time}} = Fv \text{ for a constant force}$$

conservation of energy

with no resistance,  $KE + PE$  is constant

with resistance

work done against **air resistance**  
the energy lost from that total

or friction is

On a **velocity-time graph** the **area** is the displacement and the **gradient** is the acceleration, with a negative gradient meaning **deceleration**.

## Forces and equilibrium, continued



Every mechanics problem is a picture like this. Three forces act on the climber – weight straight down, tension along the rope, and a push from the rock – and because they balance, the climber hangs still in equilibrium. Resolving each into horizontal and vertical parts turns the picture into equations

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## Exercises 2.1·2.2

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**2.1** A resultant force of 18 N acts on a 3 kg mass. Find the acceleration. [2]

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**2.2** Find the weight of a 7 kg object ( $g = 10$ ). [1]

## Exercises 2.1·2.2

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**2.1** A resultant force of 18 N acts on a 3 kg mass. Find the acceleration. [2]

**2.1**

- $a = \frac{F}{m} = \frac{18}{3} = 6 \text{ m s}^{-2}$

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**2.2** Find the weight of a 7 kg object ( $g = 10$ ). [1]

**2.2**

- $W = mg = 7 \times 10 = 70 \text{ N}$

## Exercise 3.1

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**3.1** A 5 kg mass is pulled along a smooth horizontal floor by a horizontal force of 20 N.  
Its acceleration is: [1]

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**A**  $2 \text{ m s}^{-2}$

**B**  $4 \text{ m s}^{-2}$

**C**  $5 \text{ m s}^{-2}$

**D**  $25 \text{ m s}^{-2}$

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**3.1 B**

- $a = \frac{20}{5} = 4 \text{ m s}^{-2}$

## Exercise 3.2 (a)

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**3.2** A block of mass 4 kg is released from rest on a smooth plane inclined at  $30^\circ$  to the horizontal.

(a) Find the acceleration down the slope.

[3]

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(a)

- along the slope:  $mg \sin 30^\circ = ma \Rightarrow a = g \sin 30^\circ = 10(0.5) = 5 \text{ m s}^{-2}$

## Exercise 3.2 (b)

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**3.2** A block of mass 4 kg is released from rest on a smooth plane inclined at  $30^\circ$  to the horizontal.

(b) Find the speed after it has slid 5 m.

[2]

## Exercise 3.2 (b)

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(b) Find the speed after it has slid 5 m.

[2]

(b)

- $v^2 = u^2 + 2as = 0 + 2(5)(5) = 50 \Rightarrow v = 7.07 \text{ m s}^{-1}$

## Exercise 3.3 (a)

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**3.3** Two particles of masses 3 kg and 5 kg are joined by a light inextensible string over a smooth pulley, and released from rest.

(a) Find the acceleration of the system.

[4]

## Exercise 3.3 (a)

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**3.3** Two particles of masses 3 kg and 5 kg are joined by a light inextensible string over a smooth pulley, and released from rest.

(a) Find the acceleration of the system.

[4]

(a)

- for the system,  $5g - 3g = (5 + 3)a$ ;  $20 = 8a \Rightarrow a = 2.5 \text{ m s}^{-2}$

## Exercise 3.3 (b)

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**3.3** Two particles of masses 3 kg and 5 kg are joined by a light inextensible string over a smooth pulley, and released from rest.

(b) Find the tension in the string.

[2]

## Exercise 3.3 (b)

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(b)

- for the 3 kg mass:  $T - 3g = 3a \Rightarrow T = 30 + 3(2.5) = 37.5 \text{ N}$