Connected particles

130 marks

Hints online, answers free with an account: mathswariz.uk/worksheets/a-level-mechanics-connected-particles/

Date

A Do Now

Quick questions to start. Some use earlier lessons; some set a slip that costs marks.

A1 Needed today [2 marks]

A particle of mass $3\ \text{kg}$ moves on a smooth horizontal surface. It is pushed by a horizontal force of $12\ \text{N}$ and there is a resistance of $3\ \text{N}$ to its motion. Find its acceleration.

Answer .....

A2 Needed today [3 marks]

A car starts from rest and accelerates uniformly. After $6\ \text{s}$ its speed is $15\ \text{m s}^{-1}$. Find its acceleration and the distance it travels in the $6\ \text{s}$.

Answer .....

A3 Common slip [2 marks]

A particle of mass $2\ \text{kg}$ hangs on a string. The string pulls it upwards with a force of $25\ \text{N}$. Taking upwards as positive, find its acceleration.

Answer .....

A4 Common slip [2 marks]

A box has mass $500\ \text{g}$. Find its weight, giving the unit.

Answer .....

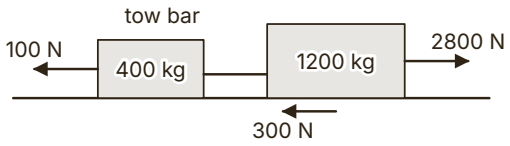
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B Example, then your turn

Your teacher works through each example with you. Then try the one beside it.

EXAMPLE 1

A car of mass $1200\ \text{kg}$ tows a trailer of mass $400\ \text{kg}$ along a straight horizontal road. They are joined by a light inextensible tow bar parallel to the road. The engine gives a driving force of $2800\ \text{N}$. The resistances to motion are $300\ \text{N}$ on the car and $100\ \text{N}$ on the trailer. Find the acceleration and the tension in the tow bar.



Hint The tow bar's tension is an internal force: it cancels when you treat the car and trailer as one body. Use the whole system for a, then one part for T.

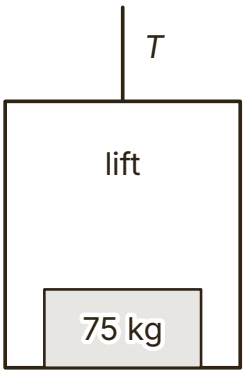
B1 A van of mass $1500\ \text{kg}$ tows a trailer of mass $500\ \text{kg}$ along a straight horizontal road using a light inextensible tow bar. The resistances to motion are $250\ \text{N}$ on the van and $150\ \text{N}$ on the trailer. The van and trailer accelerate at $0.8\ \text{m s}^{-2}$. Find the driving force and the tension in the tow bar. Explain how you used the fact that the tow bar is light. [5 marks]

Answer .....

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EXAMPLE 2

A lift of mass $600\ \text{kg}$ carries a man of mass $75\ \text{kg}$. The lift is moving upwards and slowing down at $0.6\ \text{m s}^{-2}$. Find the tension in the lift cable and the force that the man exerts on the floor of the lift.



Hint The lift is moving up and slowing down, so its acceleration is downwards. For the cable use the whole mass, $675\ \text{kg}$. For the man use his mass only, and the reaction R from the floor (not the cable).

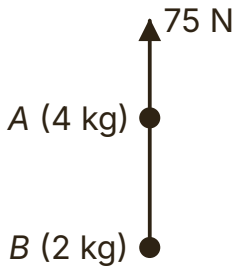
B2 A lift of mass $800\ \text{kg}$ carries a crate of mass $120\ \text{kg}$ on its floor. The lift is moving downwards and slowing down at $0.5\ \text{m s}^{-2}$. Find the tension in the cable and the force exerted by the crate on the floor, giving its direction. [6 marks]

Answer .....

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EXAMPLE 3

Two particles A and B, of masses $4\ \text{kg}$ and $2\ \text{kg}$, are joined by a light inextensible string. B hangs directly below A. A force of $75\ \text{N}$ acts vertically upwards on A. Find the acceleration of the particles and the tension in the string.



Hint The string is inextensible, so A and B have the same acceleration. The $75\ \text{N}$ acts on A only; the string pulls B up and pulls A down.

B3 Two particles P and Q, of masses $5\ \text{kg}$ and $m\ \text{kg}$, are joined by a light inextensible string. Q hangs directly below P. A force of $99\ \text{N}$ acts vertically upwards on P, and the particles accelerate upwards at $1.2\ \text{m s}^{-2}$. Find m and the tension in the string. [4 marks]

Answer .....

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EXAMPLE 4

A car of mass $1000\ \text{kg}$ tows a caravan of mass $600\ \text{kg}$ along a straight horizontal road with a light rigid tow bar. The engine is switched off and the brakes put a force of $F\ \text{N}$ on the car. The resistances are $200\ \text{N}$ on the car and $120\ \text{N}$ on the caravan. The car and caravan slow down at $2\ \text{m s}^{-2}$. Find F, and the force in the tow bar, stating whether it is a tension or a thrust.

Hint Write the tow-bar force on the caravan as T forwards. If your answer for T is negative, the tow bar is pushing the caravan backwards: it is in thrust.

B4 A car of mass $900\ \text{kg}$ tows a trailer of mass $300\ \text{kg}$ along a straight horizontal road with a light rigid tow bar. The car brakes. The resistances are $150\ \text{N}$ on the car and $90\ \text{N}$ on the trailer, and the thrust in the tow bar is $210\ \text{N}$. Find the deceleration and the braking force. The speed was $18\ \text{m s}^{-1}$ when the brakes were applied; find the time to stop. [6 marks]

Answer .....

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EXAMPLE 5

A car of mass $1000\ \text{kg}$ tows a trailer of mass $300\ \text{kg}$ along a straight horizontal road with a light tow bar. The driving force is $1680\ \text{N}$ and the resistances are $260\ \text{N}$ on the car and $120\ \text{N}$ on the trailer. (a) Find the acceleration and the tension. (b) When the speed is $10\ \text{m s}^{-1}$ the tow bar breaks. The driving force and resistances do not change. Find how far the trailer travels before it stops. (c) Find the distance between the car and the trailer when the trailer stops. Model both as particles.

Hint After the tow bar breaks there is no tension: the trailer has only its resistance acting, so it slows down. The car loses the backward pull of the tow bar, so it speeds up more.

B5 [8 marks]

A truck of mass $2400\ \text{kg}$ pulls a trailer of mass $800\ \text{kg}$ along a straight horizontal road. The driving force is $4000\ \text{N}$ and the resistances are $600\ \text{N}$ on the truck and $200\ \text{N}$ on the trailer. The truck starts from rest. After $12\ \text{s}$ the coupling breaks; the driving force and resistances do not change. Find the distance the trailer travels after the coupling breaks, and the distance between the truck and the trailer when the trailer stops.

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Answer .....

C Practice

A-Level

C1 A lift of mass $580\ \text{kg}$ carries a woman of mass $64\ \text{kg}$. The lift accelerates upwards at $0.7\ \text{m s}^{-2}$. Ravi writes $T - 644g = 580 \times 0.7$ and gets $T = 6717\ \text{N}$. Explain his mistake. Find the tension in the cable and the reaction of the floor on the woman. [5 marks]

Answer .....

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C2 A lift and a box together have mass $700\ \text{kg}$; the box has mass $20\ \text{kg}$ and rests on the floor of the lift. The tension in the cable is $7700\ \text{N}$. For the box, Mia writes $7700 + R - 20g = 20a$. Explain what is wrong with her equation. Find the acceleration and the reaction of the floor on the box. [5 marks]

Answer .....

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C3 A car tows a trailer of mass $250\ \text{kg}$. The resistance to the trailer is $175\ \text{N}$. The car and trailer are moving at $14\ \text{m s}^{-1}$ with acceleration $0.6\ \text{m s}^{-2}$ when the tow bar breaks. Lee says: "The trailer keeps accelerating at $0.6\ \text{m s}^{-2}$, so $5\ \text{s}$ later its speed is $17\ \text{m s}^{-1}$." Explain why Lee is wrong. Find the speed of the trailer $5\ \text{s}$ after the tow bar breaks, and how far it travels after the break before it stops. [6 marks]

Answer .....

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C4 An engine of mass $12\,000\ \text{kg}$ pulls two carriages P and Q, each of mass $6000\ \text{kg}$, along a straight horizontal track. P is joined to the engine and Q is joined behind P, by light rigid couplings. The driving force is $28\,000\ \text{N}$. The resistances are $2000\ \text{N}$ on the engine and $1000\ \text{N}$ on each carriage. Ben says both couplings have the same tension. Find the tension in each coupling, and explain why Ben is wrong. [7 marks]

Answer .....

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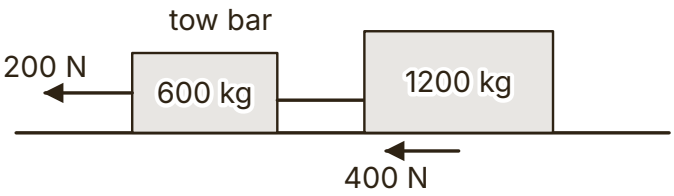
C5 Box A, of mass $3\ \text{kg}$, rests on top of box B, of mass $5\ \text{kg}$. B rests on a light tray, which is raised vertically by a rope with tension $100\ \text{N}$. Kim says that the force exerted on B by A is the weight of A, $29.4\ \text{N}$. Find the acceleration, and the correct force exerted on B by A, giving its direction. [5 marks]

Answer .....

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D1 A car of mass $1200\ \text{kg}$ tows a trailer of mass $600\ \text{kg}$ along a straight horizontal road using a light inextensible tow bar parallel to the road. The resistances to motion are modelled as constant forces of $400\ \text{N}$ on the car and $200\ \text{N}$ on the trailer. The car starts from rest with a constant driving force, and after $15\ \text{s}$ its speed is $18\ \text{m s}^{-1}$.

(a) Find the driving force. [3 marks]



Answer .....

(b) Find the tension in the tow bar. [2 marks]

Answer .....

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(c) When the speed is $18\ \mathrm{m\ s^{-1}}$ the tow bar breaks. Find the distance the trailer travels after the tow bar breaks. [3 marks]

Answer .....

(d) The driving force does not change. Find the acceleration of the car after the tow bar breaks. [2 marks]

Answer .....

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(e) Explain how you used, in part (b), the fact that the tow bar is light and inextensible. [2 marks]

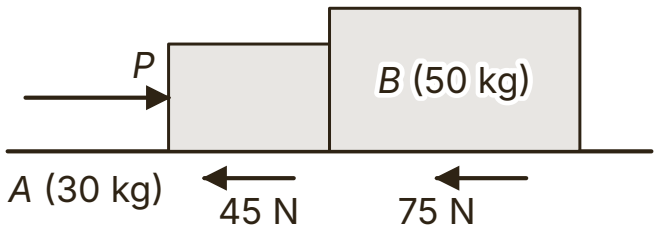
Total for D1: 12 marks

D2

Two crates A and B, of masses $30\ \text{kg}$ and $50\ \text{kg}$, stand in contact on a horizontal floor. A worker pushes A with a horizontal force of P N, so that A pushes B along in a straight line. The resistances to motion are constant forces of 45 N on A and 75 N on B. The crates start from rest and move $4\ \text{m}$ in $2\ \text{s}$. Sam says: "A passes the whole push on to B, so the force that A exerts on B is P N."

Sam is wrong.

(a) Find the value of P. [3 marks]



Answer .....

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(b) Explain Sam's error, and find the force that A exerts on B. [4 marks]

Answer .....

(c) The crates are again at rest. The worker now pushes B instead, towards A, with the same force P N, so that B pushes A. The resistances do not change. Find the force that B exerts on A. [2 marks]

Answer .....

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(d) Explain why your answers to parts (b) and (c) are different. [2 marks]

Total for D2: 11 marks

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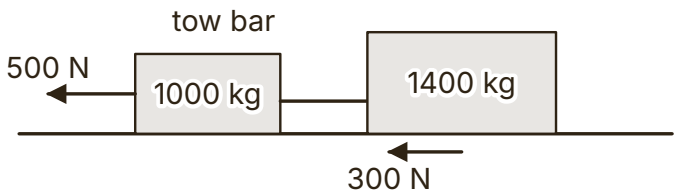
D3 Two particles A and B, of masses $3\ \text{kg}$ and $2\ \text{kg}$, are joined by a light inextensible string with B hanging directly below A. A constant force of $F\ \text{N}$ acts vertically upwards on A. The particles start from rest and rise $4\ \text{m}$ in $2\ \text{s}$. At that instant the string breaks; F does not change. Find F, and the speed of A at the instant when B is momentarily at rest. [10 marks]

Answer .....

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D4 A car of mass $1400\ \text{kg}$ tows a caravan of mass $1000\ \text{kg}$ along a straight horizontal road with a light rigid tow bar. The resistances to motion are modelled as constant forces of $300\ \text{N}$ on the car and $500\ \text{N}$ on the caravan. At first the car and caravan move at a constant $25\ \text{m s}^{-1}$.

(a) Find the driving force and the tension in the tow bar while the speed is constant. [2 marks]



Answer .....

(b) The engine is switched off and the brakes put a force of $4000\ \text{N}$ on the car. Find the deceleration. [2 marks]

Answer .....

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(c) Find the force in the tow bar while braking, and state whether it is a tension or a thrust. [3 marks]

Answer .....

(d) Find the distance travelled while braking. [2 marks]

Answer .....

(e) State one limitation of modelling the resistances as constant, and its effect on your answer to part (d). [2 marks]

Total for D4: 11 marks

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D5 A lift of mass $650\ \text{kg}$ is raised and lowered by a vertical cable. The cable will break if its tension is more than $12\,000\ \text{N}$.

(a) The lift is to accelerate upwards at $1.2\ \text{m s}^{-2}$. Find the greatest load, to the nearest kg, it can carry. [3 marks]

Answer .....

(b) The lift carries a load of $400\ \text{kg}$ and moves downwards, slowing down at $1.2\ \text{m s}^{-2}$. Find the tension in the cable. [2 marks]

Answer .....

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(c) The $400\ \text{kg}$ load is a crate of mass $370\ \text{kg}$ on the floor with a box of mass $30\ \text{kg}$ on top of it. During the motion in part (b), find the force exerted on the crate by the box, and the force exerted on the crate by the floor. [4 marks]

Answer .....

Total for D5: 9 marks

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No route is given. The hints are at the end of the sheet. Use one at a time.

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E1 A car of mass $1000\ \text{kg}$ tows a trailer of mass $m\ \text{kg}$ along a straight horizontal road with a light inextensible tow bar. The driving force is $3000\ \text{N}$. The resistance to each vehicle is $k\ \text{N}$ for every kilogram of its mass. Show that the tension in the tow bar does not depend on k. Given that the tension is $1000\ \text{N}$ and the acceleration is $1.5\ \text{m s}^{-2}$, find m and k. When the speed is $15\ \text{m s}^{-1}$ the tow bar breaks, and the driving force does not change. Find the distance between the car and the trailer $10\ \text{s}$ later, modelling both as particles. [11 marks]

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Answer .....

Extension hints

Cover these with paper. Uncover one at a time.

E1

Hint 1 Write an equation for the whole system and one for the trailer. Replace $a + k$ in one using the other.

Hint 2 The trailer equation gives $T = m(a + k)$, and the whole system gives $3000 = (1000 + m)(a + k)$.

Hint 3 After the break the trailer's only horizontal force is mk, and the car's resistance is $1000k$. Find each new acceleration and use $s = ut + \frac{1}{2}at^2$ for each.

How did it go?

Colour one circle on each line: not yet, nearly, yes.

I can find the acceleration of a connected system by treating it as a whole, and a tension or thrust by using one part of it.	○ ○ ○
I can find the tension in a lift cable and the reaction on a passenger, using the correct mass in each equation.	○ ○ ○
I can decide whether a tow bar is in tension or in thrust when a vehicle brakes.	○ ○ ○
I can work out the motion of each part after a tow bar or string breaks.	○ ○ ○

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