Pulleys

125 marks

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

Date

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A Do Now

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

A1 Last lesson [3 marks]

Particles A and B, of masses $3\ \text{kg}$ and $2\ \text{kg}$, are joined by a light inextensible string with B hanging below A. A force of $60\ \text{N}$ acts vertically upwards on A. Find the acceleration and the tension.

Answer .....

A2 Needed today [2 marks]

A particle starts from rest and moves $2\ \text{m}$ with constant acceleration $2.45\ \text{m s}^{-2}$. Find its speed.

Answer .....

A3 Needed today [3 marks]

A ball is thrown vertically upwards at $7\ \text{m s}^{-1}$. Find its greatest height above the point of release, and the time until it returns to that point.

Answer .....

A4 Common slip [2 marks]

Two forces, each of magnitude $12\ \text{N}$, act on a point: one horizontally and one vertically downwards. Find the magnitude of their resultant and the angle it makes with the horizontal.

Answer .....

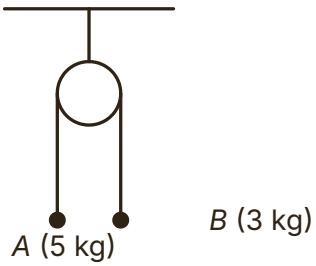
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B Example, then your turn

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

EXAMPLE 1

Particles A and B, of masses $5\ \text{kg}$ and $3\ \text{kg}$, are attached to the ends of a light inextensible string which passes over a smooth fixed pulley. The particles hang with the string taut and are released from rest. Find the acceleration of the particles, the tension in the string, and the force exerted on the pulley by the string.



Hint Write a separate equation of motion for each particle, each in its own direction of motion (A down, B up). Add them to remove T. The string pulls down on both sides of the pulley.

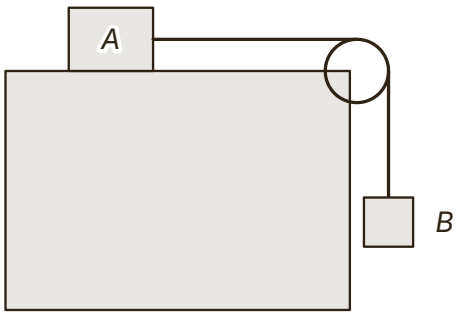
B1 Particles P and Q, of masses $6\ \text{kg}$ and $4\ \text{kg}$, hang on the ends of a light inextensible string over a smooth fixed pulley. They are released from rest. Find the acceleration, the tension, the force on the pulley, and the speed of Q after $1.5\ \text{s}$. [5 marks]

Answer .....

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EXAMPLE 2

Particle A, of mass $4\ \text{kg}$, lies on a smooth horizontal table. It is joined by a light inextensible string, which passes over a small smooth pulley at the edge of the table, to particle B, of mass $1\ \text{kg}$, hanging freely. The system is released from rest. Find the acceleration, the tension, and the magnitude and direction of the force exerted on the pulley by the string.



Hint On the table only the tension acts horizontally on A. The two parts of the string at the pulley are at right angles, each with tension T.

B2 Particle A, of mass $3\ \text{kg}$, on a smooth horizontal table is joined by a light inextensible string over a small smooth pulley at the edge to particle B, of mass $2\ \text{kg}$, hanging freely. Released from rest, find the acceleration, the tension, and the magnitude and direction of the force on the pulley. [5 marks]

Answer .....

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EXAMPLE 3

Particle A, of mass $2.5\ \text{kg}$, lies on a rough horizontal table. A light inextensible string joins A, over a small smooth pulley at the edge of the table, to particle B, of mass $1.5\ \text{kg}$, hanging freely. A constant resistance of $R\ \text{N}$ opposes the motion of A. Released from rest, B falls $0.9\ \text{m}$ in $1.2\ \text{s}$. Find the acceleration, the tension and R.

Hint Find the acceleration from the motion first (constant acceleration formulae), then use B's equation for T, then A's equation for R.

B3 [4 marks]

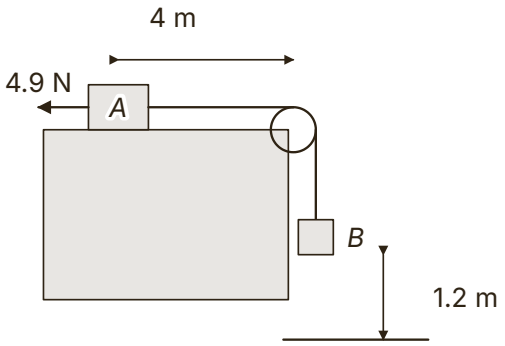
Particle A, of mass $m\ \text{kg}$, lies on a rough horizontal table and is joined over a small smooth pulley at the edge to particle B, of mass $2\ \text{kg}$, hanging freely. A constant resistance of $6\ \text{N}$ opposes the motion of A. The particles accelerate at $3.2\ \text{m s}^{-2}$. Find the tension and m.

Answer .....

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EXAMPLE 4

Particle A, of mass $2\ \text{kg}$, lies on a rough horizontal table, $4\ \text{m}$ from a small smooth pulley at the edge. A light inextensible string joins A over the pulley to particle B, of mass $3\ \text{kg}$, which hangs $1.2\ \text{m}$ above the ground. A constant resistance of $4.9\ \text{N}$ opposes the motion of A. The system is released from rest. B does not rebound when it hits the ground. Find the speed of B as it hits the ground and the total distance that A moves.



Hint Two stages. While the string is taut, A and B have the same acceleration. When B lands the string goes slack ($T = 0$): A keeps the speed it had, and only the resistance acts on it.

B4 [6 marks]

Particle A, of mass $4\ \text{kg}$, lies on a rough horizontal table, $3\ \text{m}$ from a small smooth pulley at the edge, and is joined over it by a light inextensible string to particle B, of mass $2\ \text{kg}$, which hangs $1.5\ \text{m}$ above the ground. A constant resistance of $9.8\ \text{N}$ opposes the motion of A. The system is released from rest and B does not rebound. Find the speed of B as it hits the ground, and show that A does not reach the pulley.

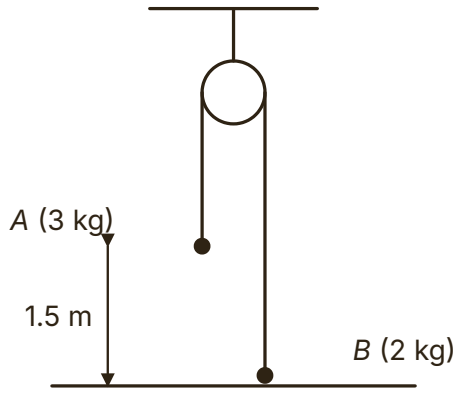
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Answer .....

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EXAMPLE 5

Particles A and B, of masses $3\ \text{kg}$ and $2\ \text{kg}$, hang on a light inextensible string over a smooth fixed pulley. A is $1.5\ \text{m}$ above the ground and B is on the ground. The system is released from rest. A does not rebound and B does not reach the pulley. Find the greatest height of B above the ground, and the time from A hitting the ground until the string is taut again.



Hint When A lands the string goes slack. B is then moving upwards with the same speed, with only its weight acting: it moves freely under gravity. The string is taut again when B comes back down to where it was when A landed.

B5 Particles A and B, of masses $5\ \text{kg}$ and $3\ \text{kg}$, hang on a light inextensible string over a smooth fixed pulley. A is $2\ \text{m}$ above the ground and B is on the ground. Released from rest, A hits the ground and does not rebound; B does not reach the pulley. Find the speed of B when A lands, the greatest height of B above the ground, and the time for which the string is slack. [7 marks]

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Answer .....

C Practice

A-Level

C1 Particles of masses $7\ \text{kg}$ and $3\ \text{kg}$ hang on a light inextensible string over a smooth fixed pulley and are released from rest. Lily writes $7g - 3g = 7a$ and gets $a = 5.6\ \text{m s}^{-2}$. Explain her mistake. Find the acceleration and the tension. [5 marks]

Answer .....

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C2 Particles of masses $8\ \text{kg}$ and $2\ \text{kg}$ hang on a light inextensible string over a smooth fixed pulley and are released from rest. Omar says the force on the pulley is the total weight, $10g = 98\ \text{N}$. Find the force on the pulley, and explain why it is less than $98\ \text{N}$. [5 marks]

Answer .....

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C3 Particle A, of mass $5\ \text{kg}$, on a smooth horizontal table is joined over a small smooth pulley at the edge to particle B, of mass $2\ \text{kg}$, hanging freely. Ben says the tension equals the weight of B, $19.6\ \text{N}$, so A accelerates at $19.6 \div 5 = 3.92\ \text{m s}^{-2}$. Explain why he is wrong, and find the correct acceleration and tension. [5 marks]

Answer .....

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C4 Particle A, of mass $1.5\ \text{kg}$, lies on a smooth horizontal table, $2.4\ \text{m}$ from a small smooth pulley at the edge. It is joined over the pulley by a light inextensible string to particle B, of mass $0.5\ \text{kg}$, hanging $1\ \text{m}$ above the ground. The system is released from rest and B does not rebound. Zara says that after B lands, A keeps accelerating at the same rate. Explain why she is wrong, and find the time from release until A reaches the pulley. [6 marks]

Answer .....

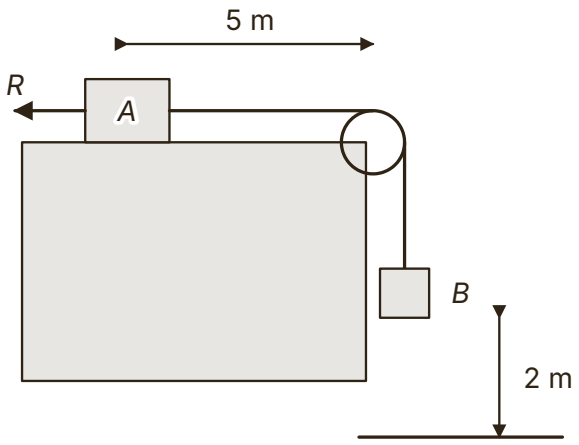
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C5 For a particle A on a table joined over a pulley to a hanging particle B, state how each of these is used when you write the equations of motion: (i) the string is inextensible, (ii) the string is light, (iii) the pulley is smooth, (iv) B does not rebound when it hits the ground. [4 marks]

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D1 Particle A, of mass $6\ \text{kg}$, lies on a rough horizontal table, $5\ \text{m}$ from a small smooth pulley fixed at the edge. A light inextensible string joins A over the pulley to particle B, of mass $4\ \text{kg}$, which hangs $2\ \text{m}$ above the ground. The resistance to the motion of A is modelled as a constant force of $R\ \text{N}$. The system is released from rest and B hits the ground $1.25\ \text{s}$ later. B does not rebound.

(a) Find the acceleration of B. [2 marks]



Answer .....

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

Answer .....

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(c) Find R. [2 marks]

Answer .....

(d) Determine whether A reaches the pulley. [4 marks]

Answer .....

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(e) State how you used, in part (b), the fact that the string is inextensible and the fact that the pulley is smooth. [2 marks]

Total for D1: 12 marks

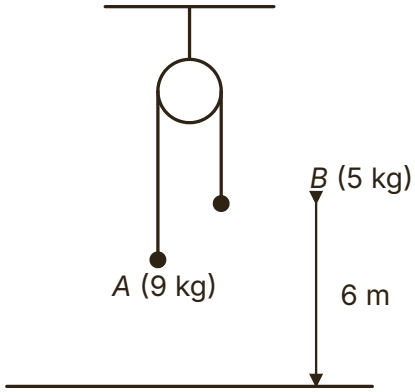
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D2

Particles A and B, of masses $9\ \text{kg}$ and $5\ \text{kg}$, hang on a light inextensible string over a smooth fixed pulley, with the hanging parts of the string vertical. B is $6\ \text{m}$ above the ground. B is projected vertically downwards with speed $4.2\ \text{m s}^{-1}$, with the string taut. A does not reach the pulley and B does not reach the ground. Tom says: "B is moving downwards, so its acceleration is downwards and it speeds up."

Tom is wrong.

(a) Explain Tom's error. Find the magnitude of the acceleration of the particles and the tension in the string. [4 marks]



Answer .....

(b) Find the least height of B above the ground. [2 marks]

Answer .....

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(c) Find the time from the moment B is projected until B is back at its starting height. [2 marks]

Answer .....

(d) Find the magnitude of the force exerted on the pulley by the string. Explain why this force is the same while B moves down and while it moves up. [3 marks]

Answer .....

Total for D2: 11 marks

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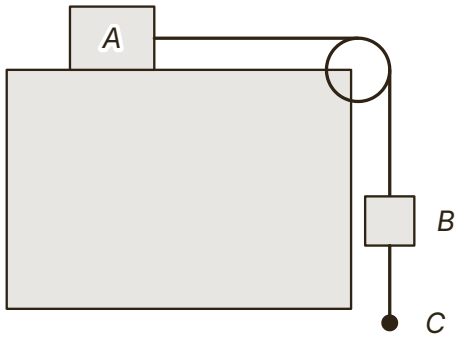
D3 Particles P and Q, of masses km and $2m$, where $k < 2$, are attached to the ends of a light inextensible string which passes over a smooth fixed pulley. The particles are released from rest with the string taut and the hanging parts vertical. Q moves downwards with acceleration $\frac{1}{4}g$. Find k, the tension in the string in terms of m and g, and the force exerted on the pulley by the string. [8 marks]

Answer .....

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D4 Particle A, of mass $3\ \text{kg}$, lies on a smooth horizontal table. A light inextensible string joins A, over a small smooth pulley at the edge of the table, to particle B, of mass $2\ \text{kg}$. A second light inextensible string joins B to particle C, of mass $1\ \text{kg}$, which hangs directly below B. The system is released from rest, and A does not reach the pulley in the motion described.

(a) Find the acceleration of the system and the tension in each string. [5 marks]



Answer .....

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(b) Find the magnitude and direction of the force exerted on the pulley by the string. [3 marks]

Answer .....

(c) After 0.5 s the string joining B and C breaks. Find the distance that A moves in the next 0.5 s. [4 marks]

Answer .....

Total for D4: 12 marks

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D5 Particle A, of mass $4\ \text{kg}$, lies on a rough horizontal table, $2.4\ \text{m}$ from a small smooth pulley at the edge. A light inextensible string joins A over the pulley to particle B, of mass $2\ \text{kg}$, which hangs $1.2\ \text{m}$ above the ground. The resistance to the motion of A is a constant force of $F\ \text{N}$. The system is released from rest. B hits the ground and does not rebound, and A comes to rest just as it reaches the pulley.

(a) Find, in terms of F, the acceleration of the system while B is falling. [2 marks]

Answer .....

(b) Show that the speed v of B as it hits the ground satisfies $v^2 = 0.4(19.6 - F)$. [2 marks]

Answer .....

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(c) Find F. [4 marks]

Answer .....

(d) Find the total time from release until A comes to rest. [3 marks]

Answer .....

Total for D5: 11 marks

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E Extension

Stretch

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

E1 Particle A, of mass $2\ \text{kg}$, lies on a rough horizontal table, $2.5\ \text{m}$ from a small smooth pulley at the edge. A light inextensible string joins A over the pulley to particle B, of mass $m\ \text{kg}$, which hangs $1\ \text{m}$ above the ground. When A moves, the resistance to its motion is a constant force of $3.92\ \text{N}$. The system is released from rest, and B does not rebound when it hits the ground. Find the range of values of m for which A moves but does not reach the pulley. [9 marks]

Answer .....

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Extension hints

Cover these with paper. Uncover one at a time.

E1

Hint 1 For A to move at all, the weight of B must be greater than the resistance.

Hint 2 Find the acceleration in terms of m, then v^2 when B lands. After that A slows down at $3.92 \div 2 = 1.96\ \text{m s}^{-2}$.

Hint 3 A must stop within the remaining $1.5\ \text{m}$. Write this as an inequality in m.

How did it go?

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

I can write an equation of motion for each particle in a pulley system and solve for the acceleration and the tension.	○ ○ ○
I can find the force that the string exerts on the pulley.	○ ○ ○
I can find the motion of each particle after one particle hits the ground or a string breaks.	○ ○ ○
I can explain how the modelling assumptions about the string and the pulley are used.	○ ○ ○

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