# Impulse in an inelastic string

95 marks

Hints online, answers free with an account: mathswariz.uk/worksheets/ocr-further-maths-mech-strings/

Date

## A Do Now

Quick questions to start.

**A1** Needed today [2 marks]

A particle of mass $2\ \mathrm{kg}$ moving at $3\ \mathrm{m\,s^{-1}}$ hits and sticks to a particle of mass $3\ \mathrm{kg}$ moving at $1\ \mathrm{m\,s^{-1}}$ in the same direction. Find their common speed.

Answer .....

**A2** Last lesson [2 marks]

A ball of mass $0.4\ \mathrm{kg}$ hits a wall at right angles at $5\ \mathrm{m\,s^{-1}}$ and rebounds at $3\ \mathrm{m\,s^{-1}}$. Find the impulse on the ball.

Answer .....

**A3** From A-Level Maths [2 marks]

A particle is projected vertically upwards at $7\ \mathrm{m\,s^{-1}}$. Find its speed when it is $2\ \mathrm{m}$ above the point of projection. Take $g = 9.8\ \mathrm{m\,s^{-2}}$.

Answer .....

**A4** From chapter 2 [2 marks]

A particle of mass $2\ \mathrm{kg}$ slows from $5\ \mathrm{m\,s^{-1}}$ to $3\ \mathrm{m\,s^{-1}}$. Find the kinetic energy it loses.

Answer .....



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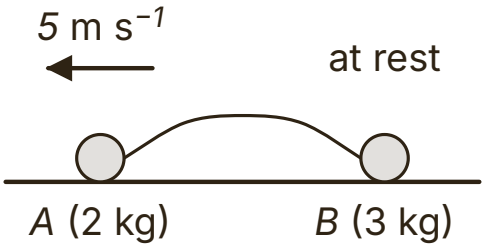
Your teacher works each example with you (I do). You try the one beside it together (We do). Then practise that part on your own (You do).

## PART 1 One particle at rest when the string becomes taut

**EXAMPLE 1 · I DO**

Particles $A$ and $B$, of masses $2\ \text{kg}$ and $3\ \text{kg}$, lie at rest on a smooth horizontal surface, joined by a light inextensible string which is slack. $A$ is projected directly away from $B$ at $5\ \text{m s}^{-1}$. Find the speed of the particles just after the string becomes taut, and the impulse in the string.




**Hint** When the string becomes taut both particles move with the same velocity. The string is not a collision, so there is no restitution.

**YOUR TURN · WE DO**

**B1** Particles $A$ and $B$, of masses $1.2\ \text{kg}$ and $0.8\ \text{kg}$, lie at rest on a smooth horizontal surface, joined by a slack light inextensible string. $A$ is projected directly away from $B$ at $4.5\ \text{m s}^{-1}$. Find the speed of the particles just after the string becomes taut, and the impulse on $B$. [4 marks]

Answer .....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**EXAMPLE 2 · I DO**

Particles $A$ and $B$ are joined by a slack light inextensible string on a smooth horizontal surface. $A$ has mass $0.4\ \text{kg}$ and is at rest. $B$, of mass $m\ \text{kg}$, is projected directly away from $A$ at $5\ \text{m s}^{-1}$. When the string becomes taut the impulse in the string has magnitude $1.2\ \text{N s}$. Find the common speed and the value of $m$.

**Hint** Use the impulse on the particle you know everything about first.

**YOUR TURN · WE DO**

**B2** Particles $A$ and $B$ are joined by a slack light inextensible string on a smooth horizontal surface. $A$ has mass $1.5\ \text{kg}$ and is at rest. $B$, of mass $m\ \text{kg}$, is projected directly away from $A$ at $7\ \text{m s}^{-1}$. When the string becomes taut the impulse in the string has magnitude $6.3\ \text{N s}$. Find the common speed and the value of $m$. [4 marks]

Answer .....


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**C1** Particles $A$ and $B$, of masses $2\ \text{kg}$ and $3\ \text{kg}$, are joined by a slack light inextensible string on a smooth horizontal surface. $A$ is at rest and $B$ is projected directly away from $A$ at $4\ \text{m s}^{-1}$. Sam writes: "When the string becomes taut, $B$ stops and $A$ moves off, so $2v = 3 \times 4$ and $A$ moves at $6\ \text{m s}^{-1}$." Explain why Sam is wrong and find the correct speed. [4 marks]

Answer .....


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**C2** Particles $A$ and $B$, of masses $0.2\ \text{kg}$ and $0.4\ \text{kg}$, lie side by side on a smooth horizontal surface, joined by a light inextensible string of length $1.5\ \text{m}$. $B$ is projected directly away from $A$ at $3\ \text{m s}^{-1}$. Find the time before the string becomes taut, the common speed after it does, and the distance $B$ moves in the first $1.2\ \text{s}$. [5 marks]

Answer .....


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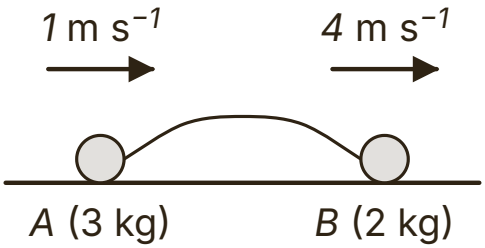
## PART 2 Both particles moving before the string becomes taut

EXAMPLE 3 · I DO

Particles $A$ and $B$, of masses $3\ \text{kg}$ and $2\ \text{kg}$, are joined by a slack light inextensible string on a smooth horizontal surface. They move in the same direction along a straight line, $B$ ahead of $A$, with $A$ at $1\ \text{m s}^{-1}$ and $B$ at $4\ \text{m s}^{-1}$. Find their common speed after the string becomes taut, and the kinetic energy lost.




**Hint** The faster particle is ahead, so the string becomes taut. Use the kinetic energy of both particles, before and after.

YOUR TURN · WE DO

**B3** Particles $A$ and $B$, of masses $2\ \text{kg}$ and $3\ \text{kg}$, are joined by a slack light inextensible string on a smooth horizontal surface. They move in the same direction, $B$ ahead of $A$, with $A$ at $0.5\ \text{m s}^{-1}$ and $B$ at $3\ \text{m s}^{-1}$. Find their common speed after the string becomes taut, the kinetic energy lost, and the impulse on $A$. [5 marks]

Answer .....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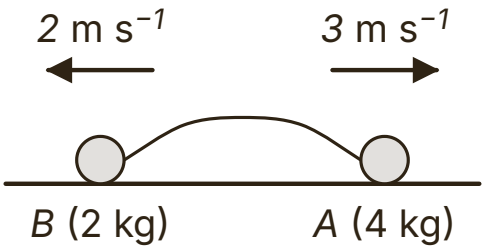
**EXAMPLE 4 · I DO**

Particles $A$ and $B$, of masses $4\ \text{kg}$ and $2\ \text{kg}$, are joined by a slack light inextensible string on a smooth horizontal surface. They move in opposite directions along a straight line, away from each other: $A$ at $3\ \text{m s}^{-1}$ and $B$ at $2\ \text{m s}^{-1}$. Find the velocity of the particles just after the string becomes taut, and the impulse on $B$.




**Hint** Choose one positive direction, so $B$'s velocity is negative. The common velocity can be in either direction: let the sign tell you.

**YOUR TURN · WE DO**

**B4** Particles $A$ and $B$, of masses $3\ \text{kg}$ and $5\ \text{kg}$, are joined by a slack light inextensible string on a smooth horizontal surface. They move in opposite directions along a straight line, away from each other: $A$ at $2\ \text{m s}^{-1}$ and $B$ at $4\ \text{m s}^{-1}$. Find the velocity of the particles just after the string becomes taut, and the impulse on $A$. [5 marks]

Answer .....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**C3** Particle $B$, of mass $0.5\ \text{kg}$, is joined by a slack light inextensible string to particle $A$, of mass $M\ \text{kg}$, on a smooth horizontal surface. $A$ is at rest and $B$ is projected directly away from $A$ at $6\ \text{m s}^{-1}$. When the string becomes taut, $75\%$ of the kinetic energy is lost. Find $M$. [5 marks]

Answer .....


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**C4** Particles $A$ and $B$, of masses $2m$ and $m$, are joined by a slack light inextensible string on a smooth horizontal surface. They move away from each other along a straight line, $A$ with speed $u$ and $B$ with speed $3u$. Alex finds the common velocity correctly, then writes: “The impulse on $A$ has size $|mv| - |mu| = 2m \times \frac{1}{3}u - 2m \times u = -\frac{4}{3}mu$, so its magnitude is $\frac{4}{3}mu$.” Find the correct impulse on $A$ and explain Alex's mistake. [5 marks]

Answer .....


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## PART 3 A string that becomes taut


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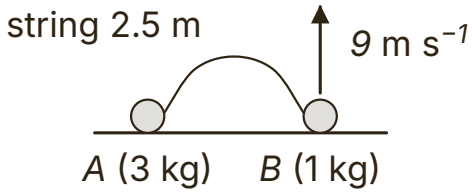
**EXAMPLE 5 · I DO**

Particle $A$, of mass $3\ \mathrm{kg}$, rests on a horizontal floor. It is joined by a light inextensible string of length $2.5\ \mathrm{m}$ to particle $B$, of mass $1\ \mathrm{kg}$, which is next to $A$. $B$ is projected vertically upwards at $9\ \mathrm{m\,s^{-1}}$. Find the speed of the particles just after $A$ is jerked off the floor, and the greatest height of $B$ above the floor. Take $g = 9.8\ \mathrm{m\,s^{-2}}$.




**Hint** First find $B$'s speed when it has risen $2.5\ \mathrm{m}$. Gravity has no impulse during the jerk, which takes no time. After the jerk, both particles rise with the same velocity and slow down at $g$.

**YOUR TURN · WE DO**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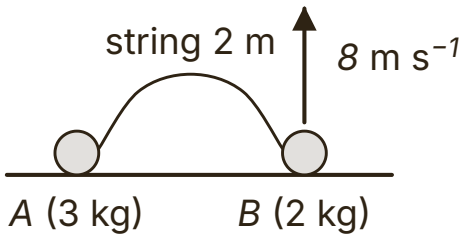
PRACTICE · YOU DO

**C5** Particle $A$, of mass $1\ \text{kg}$, rests on a horizontal floor. It is joined by a light inextensible string of length $1.8\ \text{m}$ to particle $B$, of mass $1\ \text{kg}$, which is next to $A$. $B$ is projected vertically upwards at $7.6\ \text{m s}^{-1}$. Take upwards as positive and $g = 9.8\ \text{m s}^{-2}$. Find the impulse in the string when $A$ is jerked off the floor, and the greatest height of $B$ above the floor. [6 marks]

**B5** Particle $A$, of mass $3\ \text{kg}$, rests on a horizontal floor. It is joined by a light inextensible string of length $2\ \text{m}$ to particle $B$, of mass $2\ \text{kg}$, which is next to $A$. $B$ is projected vertically upwards at $8\ \text{m s}^{-1}$. Find the speed of the particles just after $A$ is jerked off the floor, and the greatest height of $B$ above the floor. Take $g = 9.8\ \text{m s}^{-2}$. [6 marks]




Answer .....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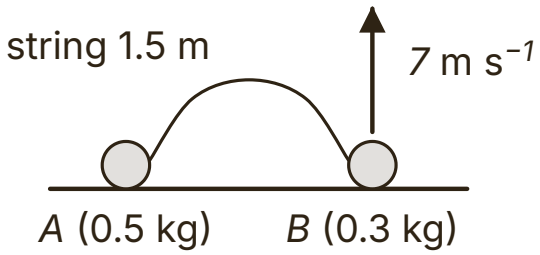
**C6** Particle $A$, of mass $0.5\ \text{kg}$, rests on a horizontal floor. It is joined by a light inextensible string of length $1.5\ \text{m}$ to particle $B$, of mass $0.3\ \text{kg}$, which is next to $A$. $B$ is projected vertically upwards at $7\ \text{m s}^{-1}$. Take $g = 9.8\ \text{m s}^{-2}$.

Answer .....




**(a)** Find the speed of $B$ just before the string becomes taut. [2 marks]

Answer .....

**(b)** Find the speed of the particles just after $A$ is jerked off the floor. [2 marks]

Answer .....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**(c)** Find the impulse on $A$, and explain why the floor exerts no impulse on $A$ during the jerk. [2 marks]

Answer .....

**(d)** Find the greatest height of $B$ above the floor, and explain why the string does not go slack while the particles rise. [3 marks]

Answer .....

**Total for C6: 9 marks**


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**D1**

> Alex writes: “The string is light, so no kinetic energy is lost when it becomes taut.”

Particles $A$ and $B$, of masses $2\ \text{kg}$ and $1\ \text{kg}$, are joined by a slack light inextensible string of length $1.2\ \text{m}$ on a smooth horizontal surface. $B$ is at rest and $A$ is projected directly away from $B$ at $6\ \text{m s}^{-1}$, towards a smooth vertical wall that is perpendicular to its path.

**(a)** Explain why Alex is wrong. [2 marks]

Answer .....

**(b)** Find the common speed after the string becomes taut, and the kinetic energy lost. [3 marks]

Answer .....


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**(c)** $A$ then hits the wall, with coefficient of restitution $\frac{1}{2}$, while the string is taut. Find the time from this impact until $A$ and $B$ collide. [2 marks]

Answer .....

**(d)** The coefficient of restitution between $A$ and $B$ is $\frac{1}{2}$. Find the velocities of $A$ and $B$ after they collide. [3 marks]

Answer .....

**Total for D1: 10 marks**


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**D2** Particles $A$ and $B$, of masses $2m$ kg and $3m$ kg, are joined by a slack light inextensible string on a smooth horizontal surface. They move away from each other along a straight line, $A$ at $5\ \mathrm{m\,s^{-1}}$ and $B$ at $u\ \mathrm{m\,s^{-1}}$, where $u < \frac{10}{3}$.

**(a)** Show that the common speed after the string becomes taut is $\dfrac{10-3u}{5}\ \mathrm{m\,s^{-1}}$, and state its direction. [2 marks]

**(b)** Describe what happens to the direction of motion of $B$. [2 marks]

Answer .....

**(c)** Find, in terms of $m$ and $u$, the impulse on $B$. [3 marks]

Answer .....


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**(d)** Show that the kinetic energy lost is $\frac{3m(u+5)^2}{5}$ J. [3 marks]

**Total for D2: 10 marks**


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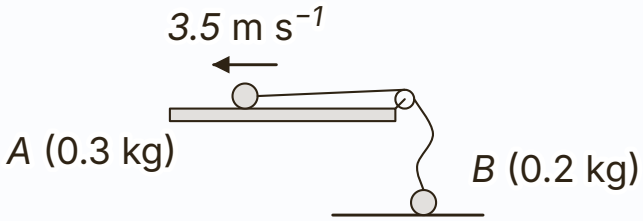
## E Extension

Stretch

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

**E1** [9 marks]

Particle $A$, of mass $0.3\ \text{kg}$, lies on a smooth horizontal table. It is attached to a light inextensible string that passes over a small smooth pulley at the edge of the table, and particle $B$, of mass $0.2\ \text{kg}$, hangs on the other end of the string. $B$ rests on the floor and the string is slack. $A$ is projected directly away from the pulley at $3.5\ \text{m s}^{-1}$. $A$ does not reach the edge of the table, and $B$ does not reach the pulley. Find the greatest height of $B$ above the floor, and the time from the jerk until $B$ is back on the floor. Take $g = 9.8\ \text{m s}^{-2}$.




Answer .....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## Extension hints

Cover these with paper. Uncover one at a time.

**E1**

**Hint 1** When the string becomes taut, it gives $A$ and $B$ impulses of the same size along the string. Gravity and the floor give $B$ no impulse during the jerk.

**Hint 2** Just after the jerk, $A$ and $B$ have the same speed, because the string is inextensible.

**Hint 3** After the jerk, write an equation of motion for each particle with the tension $T$, and solve for the acceleration.

## How did it go?

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

| | |
|---|---|
| I can find the common velocity when a string becomes taut, using conservation of momentum. | ○ ○ ○ |
| I can find the impulse in the string on each particle, with its direction. | ○ ○ ○ |
| I can find the kinetic energy lost when a string jerks particles into motion. | ○ ○ ○ |
| I can use the motion after the jerk, under gravity or a resistance. | ○ ○ ○ |


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