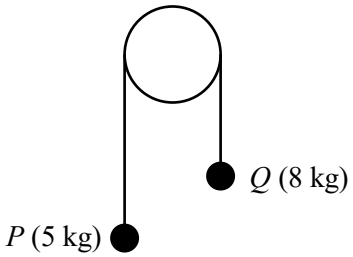
Pulleys

SCAN ME

REVISE THIS TOPIC

1



Particles P and Q have masses 5 kg and 8 kg respectively.
They are connected by a light inextensible string passing over a small smooth fixed pulley.
Initially, both particles hang freely at rest, with the string taut and the hanging parts of the string vertical.
The system is released and particle Q moves downwards. Air resistance may be ignored.

(a) Find the magnitude of the acceleration of particle Q as it descends. **(3)**

(b) Find the tension in the string. **(3)**

(c) State how the assumption that the pulley is smooth has been used. **(1)**

(a) Equation of motion for P: $T - 5g = 5a$

Equation of motion for Q: $8g - T = 8a$

Adding equations gives: $3g = 13a$

$a = \frac{3g}{13} = \mathbf{2.26\ ms^{-2}}$

(b) $T - 5g = 5(2.26\ldots)$

$T = 5(2.26\ldots) + 5g$

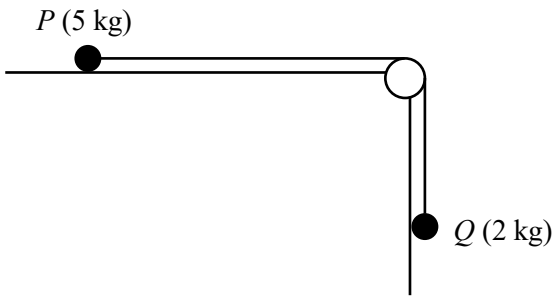
$T = \mathbf{60.3\ N}$

(c) The pulley being smooth means the tension in the string is the same on both sides of the pulley.

(Total for Question 1 is 7 marks)

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2



A particle P of mass 5 kg rests on a smooth horizontal table. P is attached to one end of a light inextensible string which passes over a small smooth pulley fixed at the edge of the table.
The other end of the string is attached to a particle Q of mass 2 kg, which hangs freely below the pulley.
Initially, the particles are at rest with the string taut and the hanging parts of the string vertical.
The system is released from rest and Q moves downwards.
Air resistance is modelled as negligible.

(a) Find the magnitude of the acceleration of the particles. **(4)**

(b) Find the tension in the string. **(2)**

The model is refined so that the table is now considered rough.

(c) State whether the magnitude of the acceleration of the particles would be greater than, less than or equal to your answer in part (a). Give a reason for your answer. **(2)**

(a) Equation of motion for P: $T = 5a$

Equation of motion for Q: $2g - T = 2a$

Adding equations gives: $2g = 7a$

$a = \frac{2g}{7} = \mathbf{2.8\ ms^{-2}}$

(b) $T = 5a$

$T = 5(2.8)$

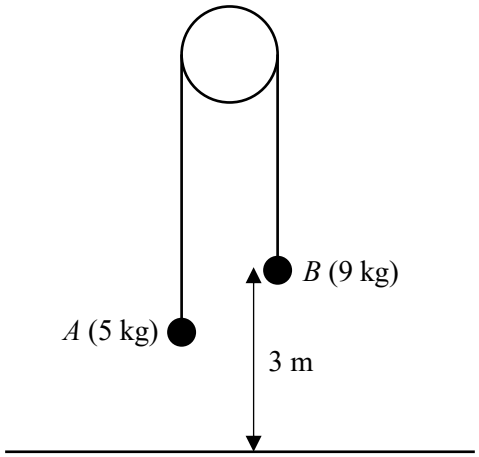
$T = \mathbf{14\ N}$

(c) The magnitude of the acceleration of the particles will be lower than in part (a) if the table is rough.
This is because friction will act against the direction of motion reducing the resultant force.

(Total for Question 2 is 8 marks)

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3



Particles A and B, of masses 5 kg and 9 kg respectively, are connected by a light inextensible string over a small smooth fixed pulley.
Initially, both particles hang freely at rest, with the string taut and the hanging parts of the string vertical.
Both particles hang freely and particle B is 3 m above the horizontal ground.
The system is released and B moves downwards.
In the subsequent motion, particle B hits the ground before particle A hits the pulley.
Air resistance is modelled as being negligible.

(a) Find the magnitude of the acceleration of particle B and the tension in the string. **(6)**

(b) Find the speed of particle B at the instant when it hits the ground. **(3)**

(c) State how the assumption that the string is inextensible has been used. **(1)**

(a) Equation of motion for A: $T - 5g = 5a$ $\quad T - 5g = 5a$

Equation of motion for B: $9g - T = 9a$ $\quad T = 5(2.8) + 5g$

Adding equations gives: $4g = 14a$ $\quad T = \mathbf{63\ N}$

$a = \dfrac{4g}{14} = \mathbf{2.8\ ms^{-2}}$

(b) $s = 3$ $\quad v^2 = u^2 + 2as$

$u = 0$ $\quad v^2 = 0^2 + 2(2.8)(3)$

$v = v$ $\quad v^2 = 16.8$

$a = 2.8$ $\quad v = \mathbf{4.1\ ms^{-1}}$

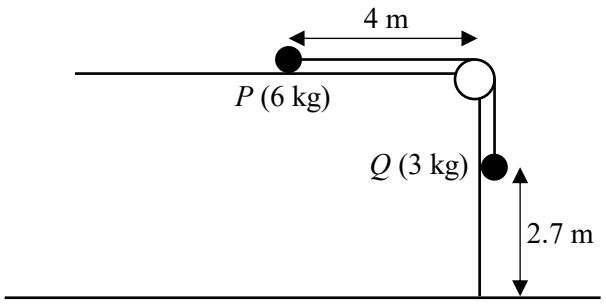
$t = t$

(c) Because the string is inextensible the magnitude of acceleration of both particles is the same.

(Total for Question 3 is 10 marks)

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4



A particle P of mass 6 kg rests on a rough horizontal table and is connected to a particle Q of mass 3 kg by a light inextensible string passing over a small smooth pulley fixed at the edge of the table.
Initially, P is 4 m from the pulley and Q hangs freely at a height of 2.7 m above horizontal ground.
The system is released from rest with the string taut.
Particle Q moves downwards and reaches the ground before P reaches the pulley.
The resistance to the motion of P is modelled as a constant force of magnitude 6.9 N.
Air resistance is modelled as negligible.

(a) Find the magnitude of the acceleration of the particles and the tension in the string. **(6)**

(b) Find the speed of Q at the instant when it hits the ground. **(3)**

(a) Equation of motion for P: $T - 6.9 = 6a$

Equation of motion for Q: $3g - T = 3a$

Adding equations gives: $3g - 6.9 = 9a$

$$a = \frac{3g - 6.9}{9} = \mathbf{2.5\ ms^{-2}}$$

$T - 6.9 = 6a$

$T - 6.9 = 6(2.5)$

$T = 6(2.5) + 6.9$

$T = \mathbf{21.9\ N}$

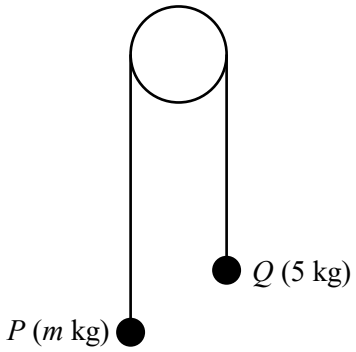
(b)

$s = 2.7$	$v^2 = u^2 + 2as$
$u = 0$	$v^2 = 0^2 + 2(2.5)(2.7)$
$v = v$	$v^2 = 13.5$
$a = 2.5$	$v = \mathbf{3.67\ ms^{-1}}$
$t = t$	

(Total for Question 4 is 9 marks)

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5



Two particles P and Q of masses m kg and 5 kg respectively, where $m > 5$, are connected by a light inextensible string passing over a small smooth fixed pulley.
Initially, both particles hang freely at rest, with the string taut and the hanging parts of the string vertical.
The system is released from rest and P descends with acceleration 4.2 ms^{-2}.
Air resistance is modelled as being negligible.

(a) Find the tension in the string. **(3)**

(b) Find the value of m. **(3)**

(c) Find the magnitude of the force exerted on the pulley by the string as P falls. **(2)**

(a) Equation of motion for Q: $T - 5g = 5a$

$T = 5a + 5g$

$T = 5(4.2) + 5(9.8)$

$T =$ **70 N**

(b) Equation of motion for P: $mg - T = ma$

$9.8m - 70 = 4.2m$

$9.8m - 4.2m = 70$

$5.6m = 70$

$m =$ **12.5**

(c) Force on pulley by string $= 2 \times T$

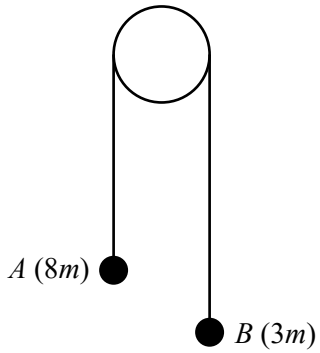
$= 2 \times 70$

$=$ **140 N**

(Total for Question 5 is 8 marks)

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6



Particles A and B, of masses $8m$ and $3m$ respectively, are connected by a light inextensible string over a small smooth fixed pulley.
Initially, both particles hang freely at rest, with the string taut and the hanging parts of the string vertical.
The system is released and A moves downwards with air resistance modelled as being negligible.

(a) Using this model, write down equations of motion for particle A and particle B. **(4)**

(b) Show that the acceleration of particle A as it moves downwards has magnitude $\frac{5g}{11}$ **(2)**

(c) Find, in terms of m and g, the tension in the string. **(2)**

The model is refined to include air resistance and a new value for the acceleration of A is calculated.

(d) State how the new value of the acceleration of particle A would compare to $\frac{5g}{11}$ **(2)**
Give a reason for your answer.

(a) Equation of motion for A: $8mg - T = 8ma$

Equation of motion for B: $T - 3mg = 3ma$

(b) Adding equations gives: $5mg = 11ma$

$5g = 11a$

$a = \frac{5g}{11}$

(c) $T - 3mg = 3ma$

$T = 3ma + 3mg$

$T = 3m\left(\frac{5g}{11}\right) + 3mg$

$T = \frac{15mg}{11} + \frac{33mg}{11}$

$T = \frac{48mg}{11}$

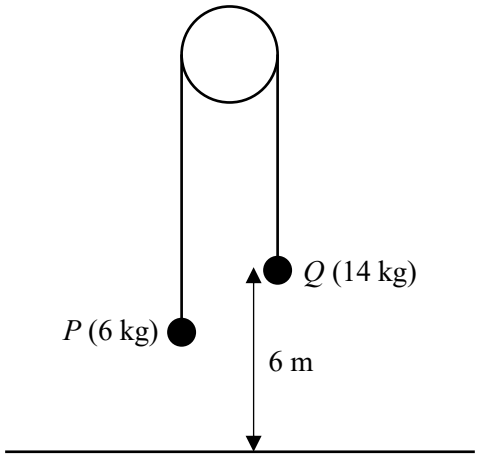
(d) If air resistance was included the value of a would be smaller than $\frac{5g}{11}$

This is because air resistance acts against the direction of motion for both particles, reducing the resultant force.

(Total for Question 6 is 10 marks)

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7



Particles P and Q, of masses 6 kg and 14 kg respectively, are connected by a light inextensible string passing over a small smooth fixed pulley.
Initially, both particles hang freely at rest, with the string taut and the hanging parts of the string vertical.
Particle Q is initially 6 m above horizontal ground.
When $t = 0$, the system is released and particle Q moves downwards reaching the ground before particle P reaches the pulley. Air resistance is modelled as being negligible.

(a) Find the magnitude of the acceleration of the particles. **(3)**

(b) Find the tension in the string. **(3)**

(c) Find the value of t when particle Q reaches the ground. **(3)**

(a) Equation of motion for P: $T - 6g = 6a$

Equation of motion for Q: $14g - T = 14a$

Adding equations gives: $8g = 20a$

$a = \frac{8g}{20} = \mathbf{3.92\ ms^{-2}}$

(b) $T - 6g = 6a$

$T = 6a + 6g$

$T = 6\left(\frac{8 \times 9.8}{20}\right) + 6(9.8)$

$T = \mathbf{82.3\ N}$

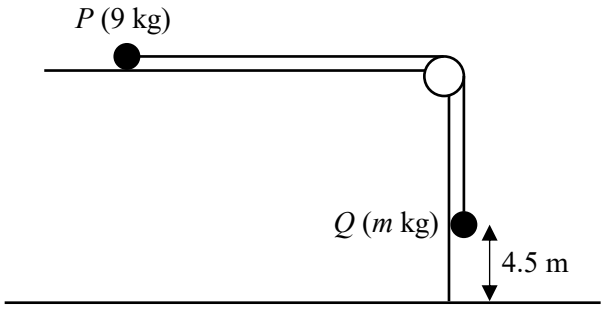
(c)

$s = 6$	$s = ut + \frac{1}{2}at^2$
$u = 0$	$6 = 0(t) + \frac{1}{2}(3.92)(t)^2$
$v = v$	$6 = 1.96t^2$
$a = 3.92$	$t^2 = \frac{6}{1.96}$
$t = t$	$t = \mathbf{1.75\ seconds}$

(Total for Question 7 is 9 marks)

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8



A particle P of mass 9 kg rests on a smooth horizontal table and is connected to a particle Q of mass m kg by a light inextensible string passing over a small smooth pulley fixed at the edge of the table.
Particle Q hangs freely below the pulley at a height of 4.5 m above horizontal ground.
Initially, the particles are at rest with the string taut and the hanging part of the string vertical.
The system is released from rest and Q accelerates vertically downwards at 2.8 ms^{-2}
In the subsequent motion, particle Q reaches the ground before particle P reaches the pulley.
Air resistance is modelled as negligible.

(a) Find the tension in the string. **(2)**

(b) Find the value of m. **(3)**

(c) Find the time taken for particle Q to reach the ground. **(3)**

(a) Equation of motion for P: $T = 9a$

Substituting $a = 2.8$ gives $T = 9(2.8)$

$T =$ **25.2 N**

(b) Equation of motion for Q: $mg - T = ma$

Substituting a and T gives $9.8m - 25.2 = 2.8m$

$9.8m - 2.8m = 25.2$

$7m = 25.2$

$m =$ **3.6**

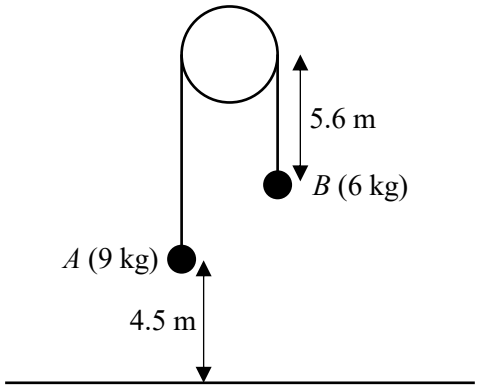
(c)

$s = 4.5$	$s = ut + \frac{1}{2}at^2$
$u = 0$	$4.5 = 0(t) + \frac{1}{2}(2.8)(t)^2$
$v = v$	$4.5 = 1.4t^2$
$a = 2.8$	$t^2 = \frac{4.5}{1.4}$
$t = t$	$t =$ **1.79 seconds**

(Total for Question 8 is 8 marks)

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9



Particles A and B, of masses 9 kg and 6 kg respectively, are connected by a light inextensible string passing over a small smooth fixed pulley.
Initially, both particles hang freely at rest, with the string taut and the hanging parts of the string vertical.
Particle A is initially 4.5 m above horizontal ground, and particle B is 5.6 m vertically below the pulley.
The system is released and A moves downwards with air resistance modelled as being negligible.
Particle A reaches the ground before particle B reaches the pulley.
When particle A reaches the ground, it remains at rest and the string becomes slack.

(a) Find the magnitude of the acceleration of the particles whilst particle A descends. **(3)**

(b) Find the tension in the string whilst particle A descends. **(3)**

(c) Find the speed of particle B at the instant A reaches the ground. **(2)**

(d) Determine whether particle B reaches the pulley. You must show your working. **(4)**

(a) Equation of motion for A: $9g - T = 9a$

Equation of motion for B: $T - 6g = 6a$

Adding equations gives: $3g = 15a$

$a = \frac{3g}{15} = \mathbf{1.96\ ms^{-2}}$

(b) $T - 6g = 6a$

$T = 6a + 6g$

$T = 6\left(\frac{3 \times 9.8}{15}\right) + 6(9.8)$

$T = \mathbf{70.6\ N}$

(c) $s = 4.5$

$u = 0$

$v = v$

$a = 1.96$

$t = t$

$v^2 = u^2 + 2as$

$v^2 = 0^2 + 2(1.96)(4.5)$

$v^2 = 17.64$

$v = \mathbf{4.2\ ms^{-1}}$

(d) $5.6 - 4.5 = 1.1$ m left to the pulley

$s = s$ $u = 4.2$ $v = v$ $a = -9.8$ $t = t$

$v^2 = u^2 + 2as$

$0^2 = (4.2)^2 + 2(-9.8)s$

$0 = 17.64 - 19.6s$

$19.6s = 17.64$

$s = 0.9$ m

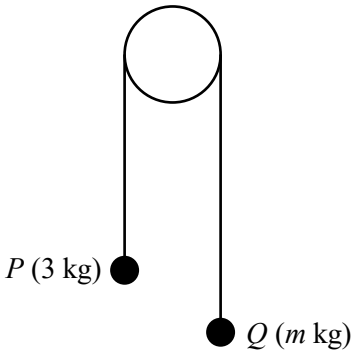
B travels an additional 0.9 m upwards but the pulley is 1.1 m away.

Therefore B does not reach the pulley.

(Total for Question 9 is 12 marks)

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10



Two particles P and Q, of masses 3 kg and m kg respectively, where $m > 3$, are connected by a light inextensible string passing over a small smooth fixed pulley.
Initially, both particles hang freely at rest, with the string taut and the hanging parts of the string vertical. The system is released and Q moves downwards with air resistance modelled as being negligible.

(a) Show that the magnitude of the acceleration of the particles is $\frac{(m-3)g}{m+3}$ **(4)**

(b) Find, in terms of m and g, the tension in the string. **(4)**

Given that the magnitude of the acceleration of the particles is less than 2.45 ms^{-2},

(c) Find the range of possible values of m. **(4)**

(a) Since $m > 3$, Q accelerates downwards and P accelerates upwards.

Equation of motion for P: $T - 3g = 3a$

Equation of motion for Q: $mg - T = ma$

Adding equations gives: $mg - 3g = ma + 3a$

$(m-3)g = (m+3)a$

$a = \frac{(m-3)g}{m+3}$

(b) $T - 3g = 3a$ [Allowed as $m > 3$ so $(m+3) > 0$]

$T = 3a + 3g$

$T = \frac{3(m-3)g}{m+3} + 3g$

$T = \frac{3(m-3)g}{m+3} + \frac{3g(m+3)}{m+3}$

$T = \frac{3(m-3)g + 3g(m+3)}{m+3}$

$T = \frac{3mg - 9g + 3mg + 9g}{m+3}$

$T = \frac{\mathbf{6mg}}{\mathbf{m+3}}$

(c) $a < 2.45$

$\frac{(m-3)g}{m+3} < 2.45$

$(m-3)g < 2.45(m+3)$

$9.8m - 29.4 < 2.45m + 7.35$

$7.35m < 36.75$

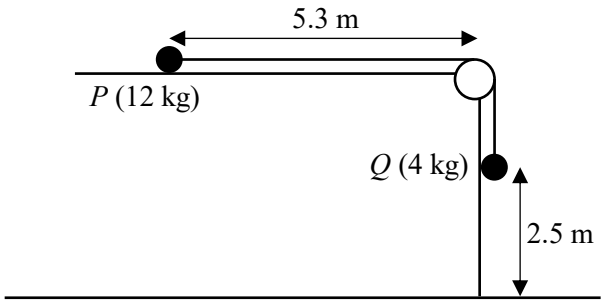
$m < 5$

But $m > 3$ given in question so $\mathbf{3 < m < 5}$

(Total for Question 10 is 12 marks)

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11



A particle P of mass 12 kg rests on a smooth horizontal table and is connected to a particle Q of mass 4 kg by a light inextensible string passing over a small smooth pulley fixed at the edge of the table. Initially, P is 5.3 m from the pulley and Q hangs freely at a height of 2.5 m above horizontal ground. The system is released from rest with the string taut.
Particle Q moves downwards, reaching the ground before P reaches the pulley.
Air resistance is modelled as negligible.

(a) Find the magnitude of the acceleration of the particles and the tension in the string. **(6)**

(b) Find the speed of Q immediately before it reaches the ground. **(3)**

Particle Q hits the ground and does not rebound.
The string becomes slack and P continues moving towards the pulley.

(c) State the magnitude of the acceleration of P while the string is slack. **(1)**

(d) Find the time taken for P to reach the pulley from the instant Q hits the ground. **(3)**

(a) Equation of motion for P: $T = 12a$

Equation of motion for Q: $4g - T = 4a$

Adding equations gives: $4g = 16a$

$a = \frac{4g}{16} = \mathbf{2.45\ ms^{-2}}$

$T = 12a$

$T = 12(2.45)$

$T = \mathbf{29.4\ N}$

(b) $s = 2.5$, $u = 0$, $v = v$, $a = 2.45$, $t = t$

$v^2 = u^2 + 2as$

$v^2 = 0^2 + 2(2.45)(2.5)$

$v^2 = 12.25$

$v = \mathbf{3.5\ ms^{-1}}$

(c) $a = \mathbf{0\ ms^{-2}}$

(String is slack so no tension means resultant force is 0)

(d) $5.3 - 2.5 = 2.8$ m left to the pulley

$s = 2.8$, $u = 3.5$, $v = 3.5$, $a = 0$, $t = t$

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

$2.8 = 3.5t + \frac{1}{2}(0)(t)^2$

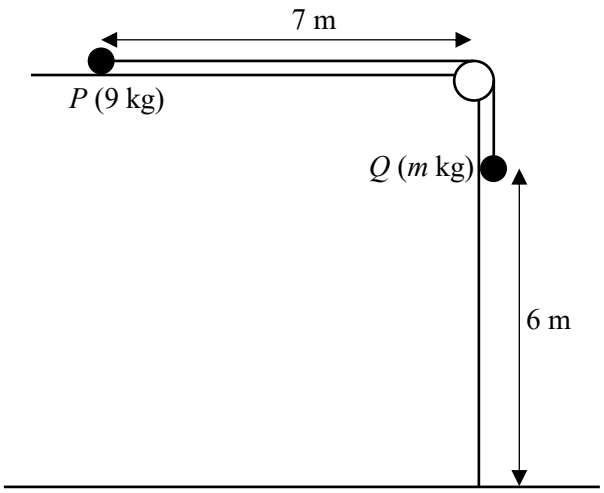
$2.8 = 3.5t$

$t = \mathbf{0.8\ seconds}$

(Total for Question 11 is 13 marks)

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12



A particle P of mass 9 kg rests on a rough horizontal table and is connected to a particle Q of mass m kg by a light inextensible string passing over a small smooth pulley fixed at the edge of the table.

Initially, P is 7 m from the pulley and Q hangs freely at a height of 6 m above horizontal ground.

The particles are at rest with the string taut.

The system is released from rest and Q accelerates vertically downwards at 2.8 ms^{-2}

The tension in the string is 42 N

The resistance to the motion of P is modelled as a constant force of magnitude R newtons.

Air resistance is modelled as negligible.

(a) Find the value of m. **(3)**

(b) Find the value of R. **(3)**

The string suddenly breaks 1.5 seconds after the particles are released.

(c) Find the speed of Q at the instant the string breaks. **(2)**

(d) Find the time taken for Q to reach the ground after the string breaks. **(5)**

(e) Determine whether P reaches the pulley before coming to rest. **(4)**

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(a) Equation of motion for Q: $mg - T = ma$ (b) Equation of motion for P: $T - R = 9a$

Substituting a and T gives $9.8m - 42 = 2.8m$ Substituting a and T gives $42 - R = 9(2.8)$

$9.8m - 2.8m = 42$ $R =$ **16.8 N**

$7m = 42$

$m =$ **6**

(c) $s = s$ $v = u + at$

$u = 0$ $v = 0 + 2.8(1.5)$

$v = v$ $v =$ **4.2 ms^{-1}**

$a = 2.8$

$t = 1.5$

(d) $s = s$ $s = ut + \frac{1}{2}at^2$

$u = 0$ $s = 0(1.5) + \frac{1}{2}(2.8)(1.5)^2$

$v = v$ $s = 3.15$ m (so Q has already fallen 3.15 m)

$a = 2.8$

$t = 1.5$ $6 - 3.15 = 2.85$ m left to fall.

$s = 2.85$ $s = ut + \frac{1}{2}at^2$

$u = 4.2$ $2.85 = 4.2t + \frac{1}{2}(9.8)(t)^2$

$v = v$ $4.9t^2 + 4.2t - 2.85 = 0$

$a = 9.8$ $t = -1.30$ seconds [disregard as negative time]

$t = t$ $t =$ **0.446 seconds**

(e) Before string breaks P and Q travel same distance (3.15 m)

$7 - 3.15 = 3.85$ m left to the pulley.

Equation of motion for P when string breaks $-16.8 = 9a$ [as there is now no tension in string]

$a = -1.8\dot{6}$ ms^{-2}

$s = s$ $v^2 = u^2 + 2as$

$u = 4.2$ $0^2 = 4.2^2 + 2(-1.8\dot{6})(s)$

$v = 0$ $0 = 17.64 - 3.7\dot{3}s$

$a = -1.8\dot{6}$ $3.7\dot{3}s = 17.64$ 4.725 m > 3.85 m

$t = t$ $s = 4.725$ m **So P does reach the pulley before coming to rest.**

(Total for Question 12 is 17 marks)

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