3.2 Newton's Second Law

Mark Scheme

Course	CIE A Level Maths
Section	2. Kinematics (Straight Line Motion)
To pi c	3.2 Newton's Second Law
D i cu lty	M ediu m

Time allowed: 80

Score: /65

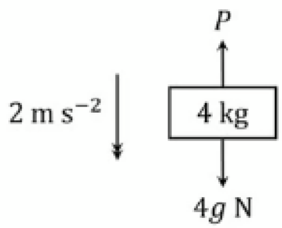
Percentage: /100

To be used by all students preparing for A Level Math
Students of other boards may also find this useful

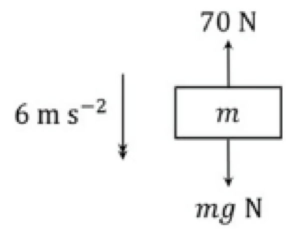
In each of the scenarios depicted below, the forces acting on the body cause it to accelerate as shown. The acceleration due to gravity is indicated by g.

Find the value of the unknown variable – acceleration (a), mass (m) or force (P) – in each case.

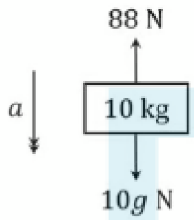
(i)



(ii)



(iii)



[6]

For motion in a straight line, $F = ma$

(Newton's Second Law of Motion)

Use $g = 10 \text{ m s}^{-2}$

Take 'down' as positive vertical direction

(i) $F = ma \Rightarrow (4g - P) = (4)(2) = 8$

$P = 4g - 8 = 4(10) - 8$

$P = 32 \text{ N}$

(ii) $F = ma \Rightarrow (mg - 70) = (m)(6) = 6m$

$mg - 6m = 70$

$m(g - 6) = 70$

$m = \frac{70}{g - 6} = \frac{70}{10 - 6}$

$m = 17.5 \text{ kg}$

(iii) $F = ma \Rightarrow (10g - 88) = (10)(a) = 10a$

$a = \frac{10g - 88}{10} = \frac{10(10) - 88}{10}$

$a = 1.2 \text{ m s}^{-2}$

As part of a stage show, a singer is lifted up into the air by a cable attached to a special harness. The singer has a mass of 54 kg, and at the start of the lift is standing stationary on the floor. The singer accelerates vertically upwards at a constant rate, and after 2 seconds has reached a height of 3 metres.

$u = 0$

$t = 2$ $s = 3$

(a) By using the appropriate *suvat* formula, determine the acceleration experienced by the singer during the lift. a

[3]

(b) Find the tension in the cable during the lift.

[2]

After singing the show's grand finale, the singer is lowered vertically downwards back to the floor. During the initial part of the descent the downwards acceleration is constant, and its magnitude is the same as the magnitude of the upwards acceleration while the singer was being lifted.

(c) Find the tension in the cable during the initial part of the descent.

[2]

a) We know u, t and s, and want to know a.

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

$$3 = (0)(2) + \frac{1}{2}a(2)^2$$

$$3 = 2a$$

$$a = 1.5 \text{ ms}^{-2}$$

As part of a stage show, a singer is lifted up into the air by a cable attached to a special harness. The singer has a mass of 54 kg, and at the start of the lift is standing stationary on the floor. The singer accelerates vertically upwards at a constant rate, and after 2 seconds has reached a height of 3 metres.

(a) By using the appropriate *suvat* formula, determine the acceleration experienced by the singer during the lift.

$a = 1.5 \text{ ms}^{-2}$

[3]

(b) Find the tension in the cable during the lift.

[2]

After singing the show's grand finale, the singer is lowered vertically downwards back to the floor. During the initial part of the descent the downwards acceleration is constant, and its magnitude is the same as the magnitude of the upwards acceleration while the singer was being lifted.

(c) Find the tension in the cable during the initial part of the descent.

[2]

b)

Drawing a diagram really helps!

Take 'up' as positive vertical direction

$$F = ma$$

$$(T - 54g) = (54)(1.5) = 81$$

$$T = 81 + 54g = 81 + 54(10) = 621$$

$T = 621 \text{ N}$

use $g = 10 \text{ ms}^{-2}$

As part of a stage show, a singer is lifted up into the air by a cable attached to a special harness. The singer has a mass of 54 kg, and at the start of the lift is standing stationary on the floor. The singer accelerates vertically upwards at a constant rate, and after 2 seconds has reached a height of 3 metres.

(a) By using the appropriate *suvat* formula, determine the acceleration experienced by the singer during the lift.

$a = 1.5 \text{ ms}^{-2}$

[3]

(b) Find the tension in the cable during the lift.

[2]

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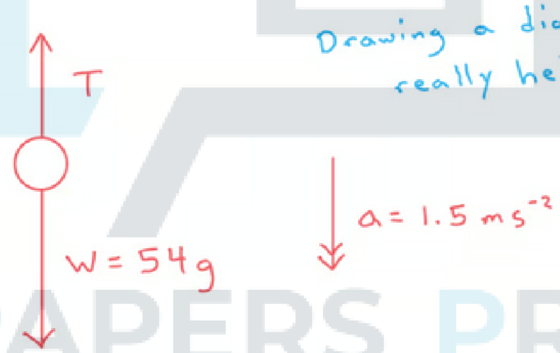
[2]

c)

Drawing a diagram really helps!



Take 'down' as positive vertical directio

$F = ma$

$(54g - T) = (54)(1.5) = 81$

$T = 54g - 81 = 54(10) - 81 = 459$

$T = 459 \text{ N } (3 \text{ s.f.})$

use $g = 10 \text{ ms}^{-2}$

A child is pulling a cart along a horizontal path by means of a horizontal rope attached to its front end. The cart has a total mass of 15 kg, and as it moves it experiences a constant resistance to motion of magnitude 2 N. The cart starts at rest and accelerates at a constant rate, and after 5 seconds it has reached a speed of 2 m s^{-1}.

$t = 5$ $v = 2$

Find:

(a) the acceleration of the cart

[3]

(b) the tension in the rope.

[2]

Constant acceleration means we can use suvat

a) We know u, t and v, and want to know a.

$$v = u + at$$
$$2 = 0 + a(5) = 5a$$

$$a = 0.4 \text{ ms}^{-2}$$

A child is pulling a cart along a horizontal path by means of a horizontal rope attached to its front end. The cart has a total mass of 15 kg, and as it moves it experiences a constant resistance to motion of magnitude 2 N. The cart starts at rest and accelerates at a constant rate, and after 5 seconds it has reached a speed of 2 m s^{-1}.

Find:

(a) the acceleration of the cart

[3]

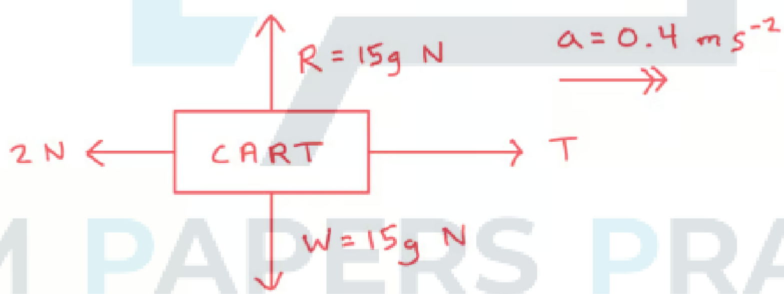
(b) the tension in the rope.

[2]

$a = 0.4 \text{ m s}^{-2}$ (from part (a))

Drawing a diagram really helps!

b)



Vertical forces are balanced.

Take 'right' as positive horizontal direction.

In horizontal direction:

$$F = ma$$
$$(T - 2) = (15)(0.4)$$
$$T - 2 = 6$$
$$T = 8 \text{ N}$$

Two particles A and B are connected by a light inextensible string. Particle A has a mass of 5 kg, particle B has a mass of 15 kg, and particle B hangs directly below particle A. A force of 300 N is applied vertically upwards on particle A, causing the particles to accelerate.

Find:

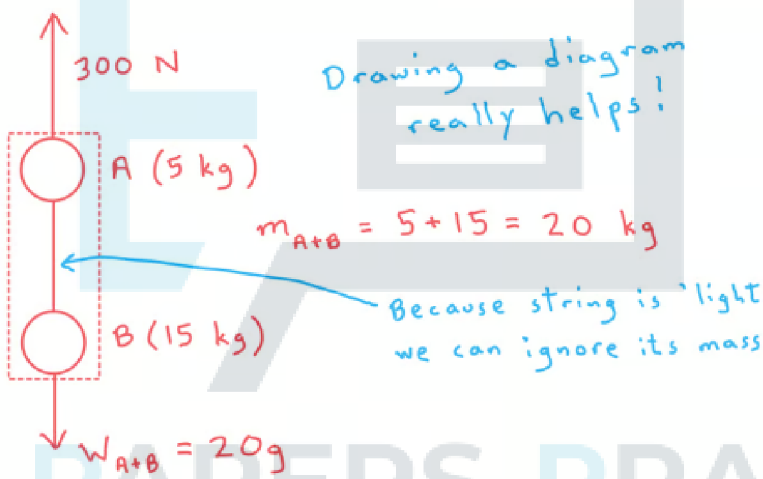
(a) the magnitude of the acceleration

[3]

(b) the tension in the string.

[2]

a)



Treat 2 masses as single object here.

Take 'up' as positive vertical direction

Then:

$$F = ma$$

$$(300 - 20g) = (20)(a)$$

use $g = 10\ ms^{-2}$

$$a = \frac{300 - 20g}{20} = \frac{300 - 20(10)}{20}$$

$$a = 5\ ms^{-2}$$

Two particles A and B are connected by a light inextensible string. Particle A has a mass of 5 kg, particle B has a mass of 15 kg, and particle B hangs directly below particle A. A force of 300 N is applied vertically upwards on particle A, causing the particles to accelerate.

Find:

(a) the magnitude of the acceleration

$a = 5 \text{ ms}^{-2}$

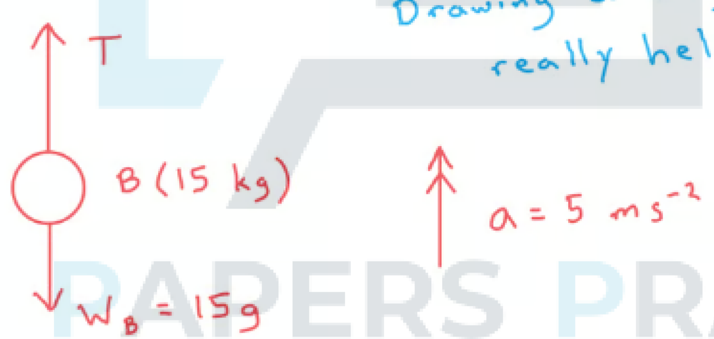
[3]

(b) the tension in the string.

[2]

b) Here just consider forces on mass B

Drawing a diagram really helps!



Take 'up' as positive vertical direction

$$F = ma$$

$$(T - 15g) = (15)(5) = 75$$

$$T = 75 + 15g = 75 + 15(10)$$

$$T = 225 \text{ N}$$

use $g = 10 \text{ ms}^{-2}$

A train locomotive of mass 7000 kg and a carriage of mass 2000 kg are at rest on a section of horizontal track. The connection between the locomotive and carriage may be modelled as a light rod parallel to the direction of their motion forward or backward along the track. The resistances to motion of the locomotive and the carriage are modelled as constant forces of 2300 N and 1000 N respectively.

The locomotive begins to accelerate in the backwards direction, with its engine providing a constant driving force of 15 000 N.

Find:

(a) the magnitude of the acceleration of the locomotive and carriage

[3]

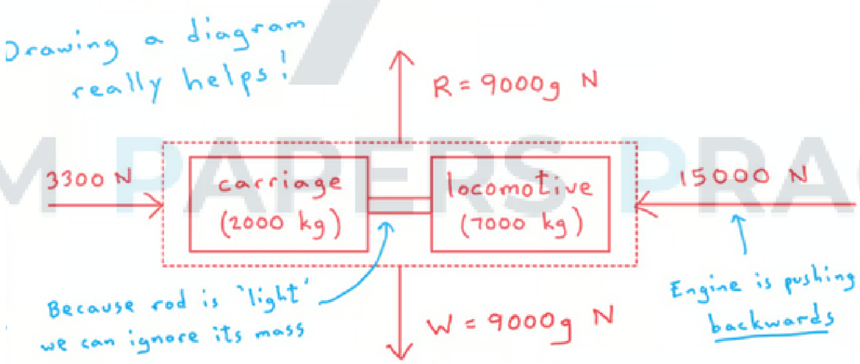
(b) the thrust in the connecting rod.

[2]

a) Treat locomotive and carriage as single object here.

Total mass = 7000 + 2000 = 9000 kg

Total resistance = 2300 + 1000 = 3300 N



Vertical forces are balanced.

Take 'left' as positive horizontal direction.

In horizontal direction:

$$F = ma$$

$$(15000 - 3300) = (9000)(a)$$

$$a = \frac{15000 - 3300}{9000}$$

$$a = 1.3 \text{ ms}^{-2}$$

A train locomotive of mass 7000 kg and a carriage of mass 2000 kg are at rest on a section of horizontal track. The connection between the locomotive and carriage may be modelled as a light rod parallel to the direction of their motion forward or backward along the track. The resistances to motion of the locomotive and the carriage are modelled as constant forces of 2300 N and 1000 N respectively.

The locomotive begins to accelerate in the backwards direction, with its engine providing a constant driving force of 15000 N.

Find:

(a) the magnitude of the acceleration of the locomotive and carriage

[3]

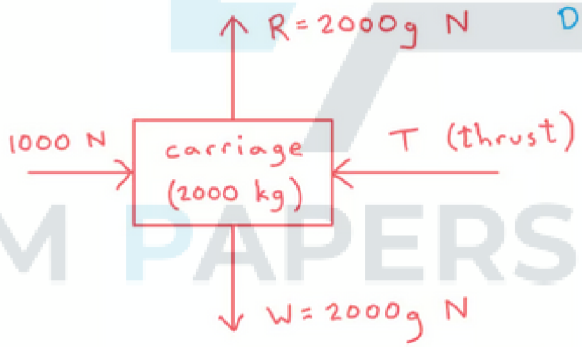
(b) the thrust in the connecting rod.

[2]

$a = 1.3 \text{ m s}^{-2}$ (from part (a))

b) Here only consider forces on the carriage.

Drawing a diagram really helps!



Vertical forces are balanced.

Take 'left' as positive horizontal direction.

In horizontal direction:

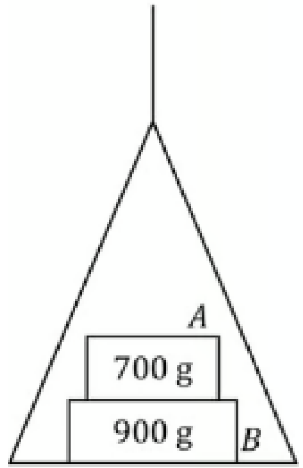
$$F = ma$$

$$(T - 1000) = (2000)(1.3) = 2600$$

$$T = 2600 + 1000$$

$$\boxed{T = 3600 \text{ N}}$$

Two masses A and B are placed in a light scale-pan, with mass A resting on top of mass B as shown in the diagram below:



Mass A has a mass of 700 g and mass B has a mass of 900 g. The scale-pan is attached to a vertical light inextensible string.

Using the string, the scale-pan is raised vertically with an acceleration of 0.5 m s^{-2}.

Find:

(a) the tension in the string

[3]

(b) the force exerted on mass A by mass B

[2]

(c) the force exerted on mass B by mass A

[1]

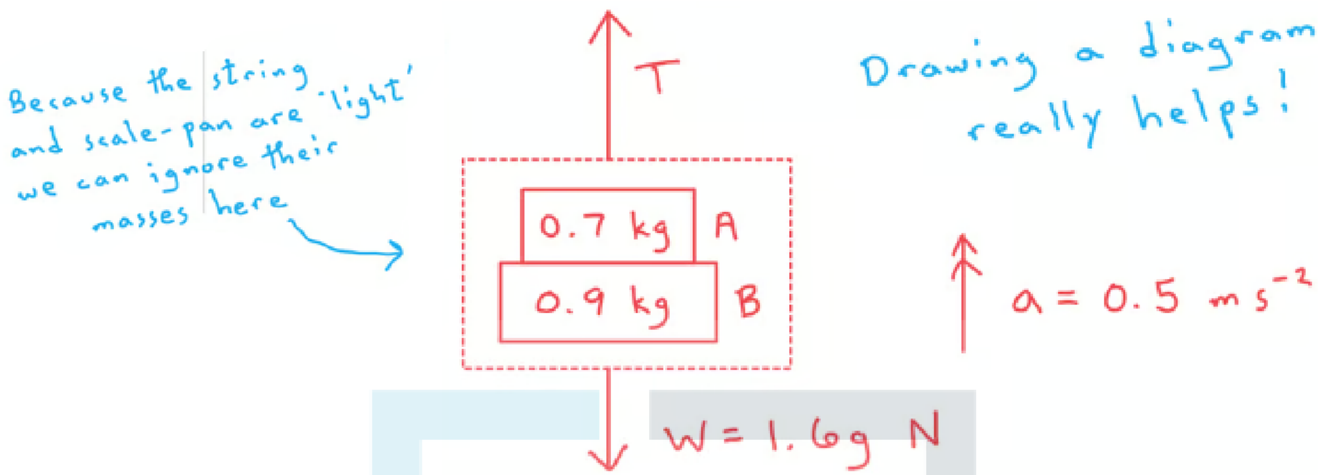
(d) the force exerted on mass B by the scale-pan.

[2]

a) $m_A = 0.7$ kg $\quad m_B = 0.9$ kg ← Convert to standard units

Treat the two masses as single object here.

Combined mass = $0.7 + 0.9 = 1.6$ kg



Take 'up' as positive vertical direction.

$$F = ma$$

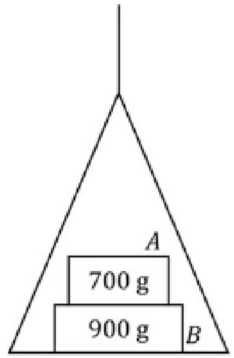
$$(T - 1.6g) = (1.6)(0.5) = 0.8$$

$$T = 0.8 + 1.6g = 0.8 + 1.6(10)$$

use $g = 10$ ms^{-2}

$$\boxed{T = 16.8 \text{ N}}$$

Two masses A and B are placed in a light scale-pan, with mass A resting on top of mass B as shown in the diagram below:



Mass A has a mass of 700 g and mass B has a mass of 900 g. The scale-pan is attached to a vertical light inextensible string.

Using the string, the scale-pan is raised vertically with an acceleration of 0.5 m s^{-2}.

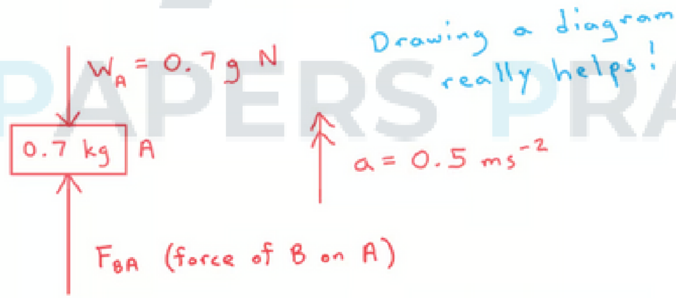
Find: (a) the tension in the string [3]

(b) the force exerted on mass A by mass B [2]

(c) the force exerted on mass B by mass A [1]

(d) the force exerted on mass B by the scale-pan. [2]

b) Here only consider the forces on mass A.



Take 'up' as positive vertical direction.

$$F = ma$$

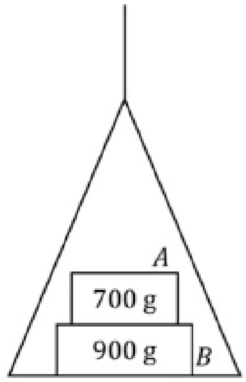
$$(F_{BA} - 0.7g) = (0.7)(0.5) = 0.35$$

$$F_{BA} = 0.35 + 0.7g = 0.35 + 0.7(10)$$

use $g = 10 \text{ ms}^{-2}$

$$F_{BA} = 7.35 \text{ N up}$$

Two masses A and B are placed in a light scale-pan, with mass A resting on top of mass B as shown in the diagram below:



Mass A has a mass of 700 g and mass B has a mass of 900 g. The scale-pan is attached to a vertical light inextensible string.

Using the string, the scale-pan is raised vertically with an acceleration of 0.5 m s^{-2}.

Find:

(a) the tension in the string

[3]

(b) the force exerted on mass A by mass B

$F_{BA} = 7.35$ N up

[2]

(c) the force exerted on mass B by mass A

[1]

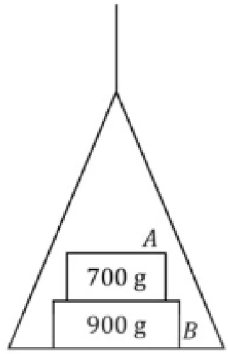
(d) the force exerted on mass B by the scale-pan.

[2]

c) By Newton's Third Law, the force of A on B is equal in magnitude but opposite in direction to the force of B on A.

The force of A on B is 7.35 N vertically downwards.

Two masses A and B are placed in a light scale-pan, with mass A resting on top of mass B as shown in the diagram below:



Mass A has a mass of 700 g and mass B has a mass of 900 g. The scale-pan is attached to a vertical light inextensible string.

Using the string, the scale-pan is raised vertically with an acceleration of 0.5 m s^{-2}.

Find:

(a) the tension in the string

[3]

(b) the force exerted on mass A by mass B

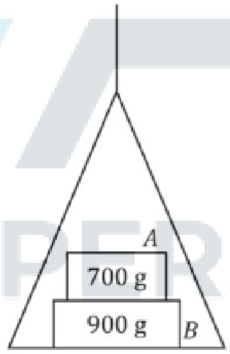
[2]

(c) the force exerted on mass B by mass A

The force of A on B is 7.35 N vertically downwards.

[1]

Two masses A and B are placed in a light scale-pan, with mass A resting on top of mass B as shown in the diagram below:



Mass A has a mass of 700 g and mass B has a mass of 900 g. The scale-pan is attached to a vertical light inextensible string.

Using the string, the scale-pan is raised vertically with an acceleration of 0.5 m s^{-2}.

Find (a) the tension in the string

(b) the force exerted on mass A by mass B

[2]

(c) the force exerted on mass B by mass A

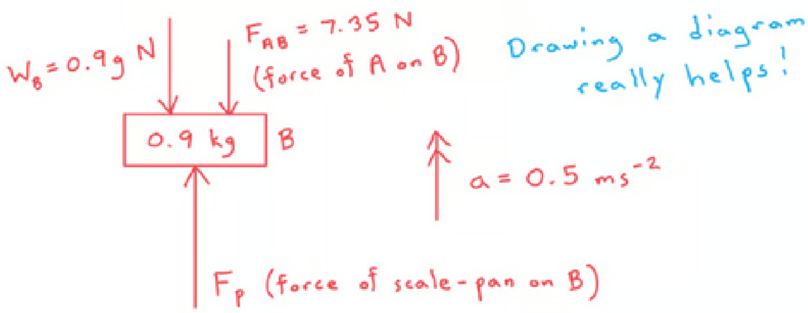
The force of A on B is 7.35 N vertically downwards.

[1]

(d) the force exerted on mass B by the scale-pan.

[2]

d) Here only consider the forces on mass B.



Take 'up' as positive vertical direction.

$$F = ma$$

$$(F_p - 0.9g - 7.35) = (0.9)(0.5) = 0.45$$

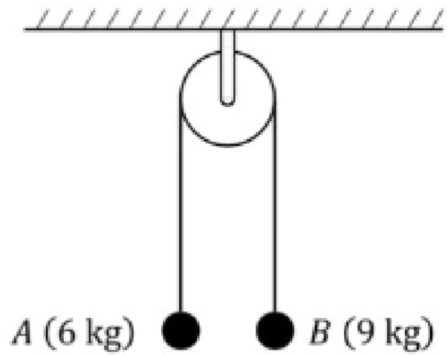
$$F_p = 0.45 + 7.35 + 0.9g$$

$$= 7.8 + 0.9g = 7.8 + 0.9(10)$$

use $g = 10 \text{ ms}^{-2}$

$$F_p = 16.8 \text{ N}$$

Two particles A and B have masses of 5 kg and 9 kg respectively. The particles are connected by a light inextensible string that passes over a smooth light fixed pulley as shown in the diagram below:

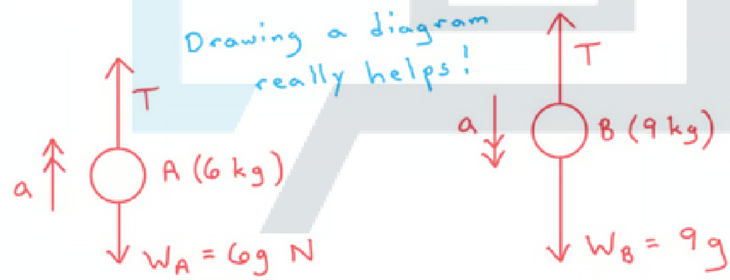


The particles are released from rest with the string taut.

Calculate the acceleration of the particles and the tension in the string as B descends.

Consider the forces on A and B separately:

Drawing a diagram really helps!



Take 'up' as the positive direction

$F = ma$

$T - 6g = 6a$ equation ①

Take 'down' as the positive direction

$F = ma$

$9g - T = 9a$ equation ②

← simultaneous equations →

$$\begin{aligned} ① \quad & T - 6g = 6a \\ + ② \quad & +(9g - T = 9a) \\ \hline & 3g = 15a \end{aligned}$$

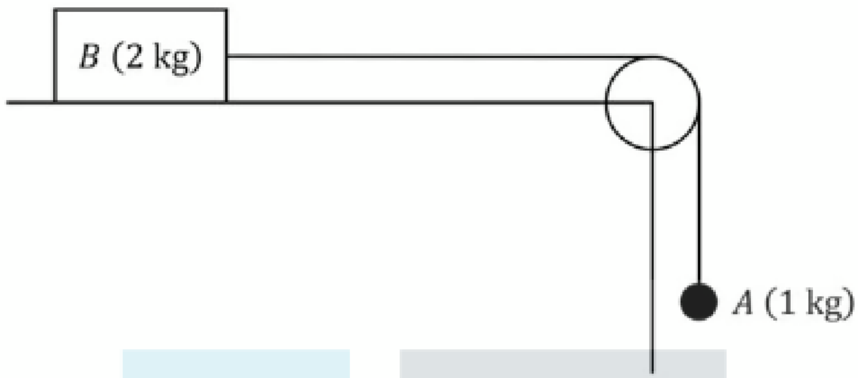
use $g = 10$ ms^{-2}

$$\Rightarrow a = \frac{3g}{15} = \frac{1}{5}(10) = 2 \text{ ms}^{-2}$$

$$\Rightarrow T = 6a + 6g = 6(2) + 6(10) = 72 \text{ N}$$

from ①

A box B of mass 2 kg rests on a rough horizontal table. It is connected by a light inextensible string to a metal sphere A of mass 1 kg. The string passes over a smooth light fixed pulley at the edge of the table so that A is hanging vertically downwards as shown in the diagram below:



The string between B and the pulley is horizontal, and the magnitude of the frictional force between B and the table is 7.6 N.

The system is released from rest with the string taut.

(a) Calculate the acceleration of the two objects and the tension in the string as A descends.

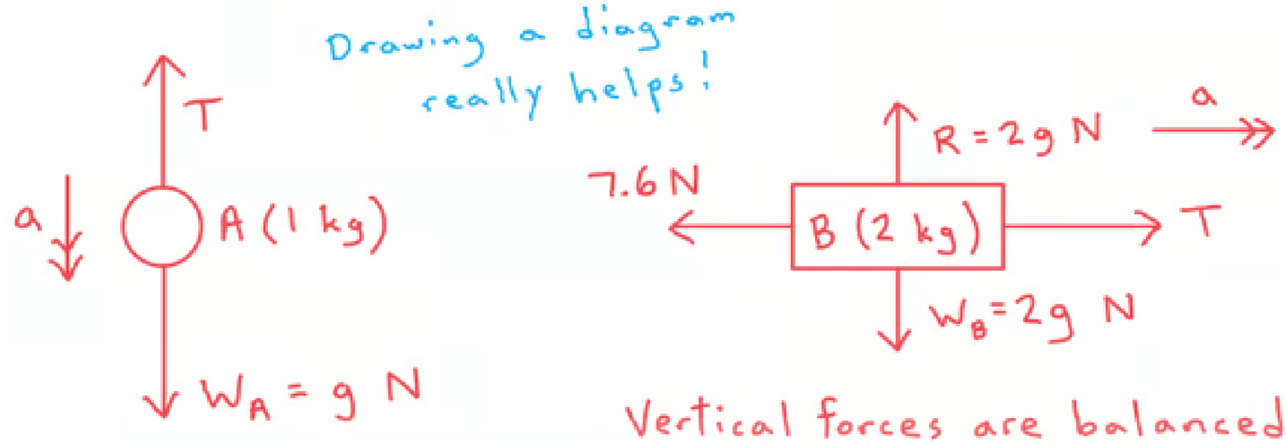
[4]

After descending for 1.5 seconds, sphere A strikes the ground and immediately comes to rest. At that moment, box B is exactly 14 cm from the pulley.

(b) By first calculating the speed of B at the moment A hits the ground, and then employing an appropriate equation of motion, determine whether or not B will strike the pulley before friction causes it to come to rest.

[4]

a) Consider the forces on A and B separately:



Vertical forces are balanced

Take 'down' as the positive direction

$F = ma$

$g - T = a$ equation ①

Take 'right' as the positive horizontal direction

$F = ma$

$T - 7.6 = 2a$ equation ②

(simultaneous equations)

① $\quad g - T = a$

$+$ ② $\quad + (T - 7.6 = 2a)$

$$g - 7.6 = 3a$$

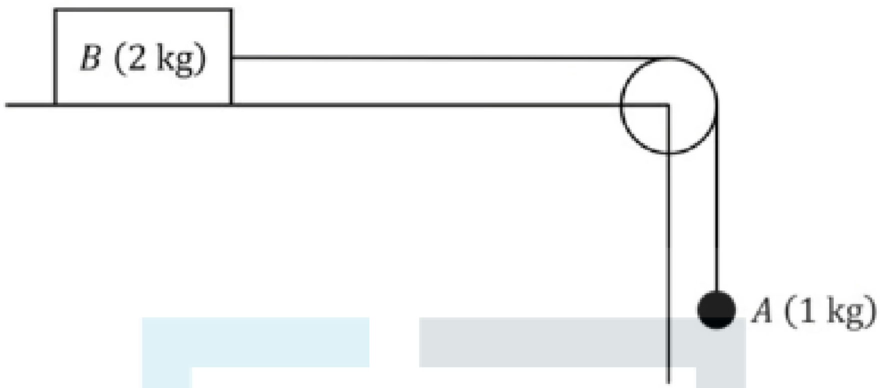
use $g = 10 \text{ ms}^{-2}$

$$\Rightarrow a = \frac{g - 7.6}{3} = \frac{10 - 7.6}{3} = 0.8 \text{ ms}^{-2}$$

$$\Rightarrow T = 2a + 7.6 = 2(0.8) + 7.6 = 9.2 \text{ N}$$

(from ②)

A box B of mass 2 kg rests on a rough horizontal table. It is connected by a light inextensible string to a metal sphere A of mass 1 kg. The string passes over a smooth light fixed pulley at the edge of the table so that A is hanging vertically downwards as shown in the diagram below:



The string between B and the pulley is horizontal, and the magnitude of the frictional force between B and the table is 7.6 N.

The system is released from rest with the string taut.

(a) Calculate the acceleration of the two objects and the tension in the string as A descends.

$a = 0.8\ \text{ms}^{-2}$ $T = 9.2\ \text{N}$

[4]

After descending for 1.5 seconds, sphere A strikes the ground and immediately comes to rest. At that moment, box B is exactly 14 cm from the pulley.

(b) By first calculating the speed of B at the moment A hits the ground, and then employing an appropriate equation of motion, determine whether or not B will strike the pulley before friction causes it to come to rest.

[4]

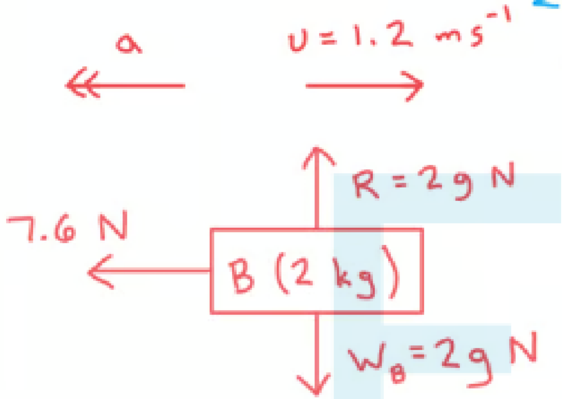
b) After 1.5 s the velocity of B is

$$v = u + at = 0 + (0.8)(1.5) = 1.2 \text{ ms}^{-1}$$

$u = 0$ ("released from rest")

When A hits the ground, the string goes slack.

Consider the forces on B: (v in the first part becomes u here in the second part)



Vertical forces are balanced

Take 'right' as the positive horizontal direction

$$F = ma$$

$$-7.6 = 2a \Rightarrow a = -3.8 \text{ ms}^{-2}$$

Before coming to rest from friction, B would move a distance of:

$$v^2 = u^2 + 2as \Rightarrow s = \frac{v^2 - u^2}{2a}$$

$$\Rightarrow s = \frac{0^2 - 1.2^2}{2(-3.8)} = \frac{1.2^2}{7.6} = 0.189 \text{ m} = 18.9 \text{ cm (3 s.f.)}$$

18.9 cm > 14 cm, so B will strike the pulley before it comes to rest.