Mechanics 1: Connected Bodies (N3L)

Past Exam Questions
2006 - 2013

Name:

January 2013

4 A tractor, of mass 3500 kg, is used to tow a trailer, of mass 2400 kg, across a horizontal field. The trailer is connected to the tractor by a horizontal tow bar. As they move, a constant resistance force of 800 newtons acts on the trailer and a constant resistance force of R newtons acts on the tractor. A forward driving force of 2500 newtons acts on the tractor. The trailer and tractor accelerate at $0.2\,\mathrm{m\,s^{-2}}$.

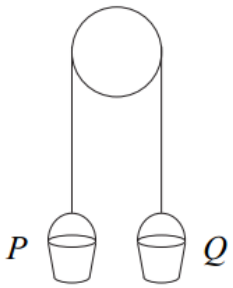
(a) Find R. *(3 marks)*

(b) Find the magnitude of the force that the tow bar exerts on the trailer. *(3 marks)*

(c) State the magnitude of the force that the tow bar exerts on the tractor. *(1 mark)*

January 2006

7 A builder ties two identical buckets, P and Q, to the ends of a light inextensible rope. He hangs the rope over a smooth beam so that the buckets hang in equilibrium, as shown in the diagram.



The buckets are each of mass 0.6 kg.

(a) (i) State the magnitude of the tension in the rope. *(1 mark)*

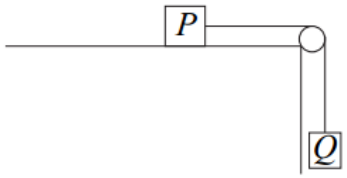
(ii) State the magnitude and direction of the force exerted on the beam by the rope. *(2 marks)*

(b) The bucket Q is held at rest while a stone, of mass 0.2 kg, is placed inside it. The system is then released from rest and, in the subsequent motion, bucket Q moves vertically downwards with the stone inside.

(i) By forming an equation of motion for each bucket, show that the magnitude of the tension in the rope during the motion is 6.72 newtons, correct to three significant figures. *(6 marks)*

(ii) State the magnitude of the force exerted on the beam by the rope while the motion takes place. *(1 mark)*

5 A small block P is attached to another small block Q by a light inextensible string. The block P rests on a rough horizontal surface and the string hangs over a smooth peg so that Q hangs freely, as shown in the diagram.



The block P has mass 0.4 kg and the coefficient of friction between P and the surface is 0.5.

The block Q has mass 0.3 kg.

The system is released from rest and Q moves vertically downwards.

(a) (i) Draw a diagram to show the forces acting on P. *(1 mark)*

(ii) Show that the frictional force between P and the surface has magnitude 1.96 newtons. *(2 marks)*

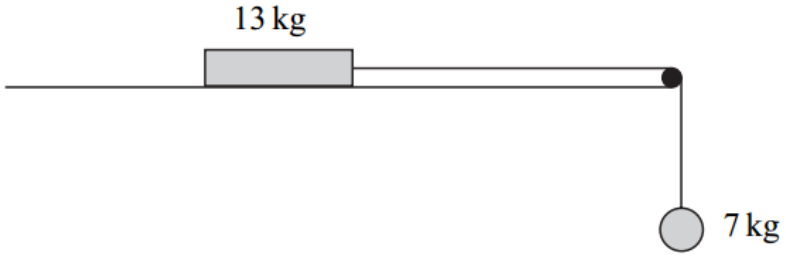
(b) By forming an equation of motion for each block, show that the magnitude of the acceleration of each block is $1.4\,\text{m}\,\text{s}^{-2}$. *(5 marks)*

(c) Find the speed of the blocks after 3 seconds of motion. *(2 marks)*

(d) After 3 seconds of motion, the string breaks. The blocks continue to move. Comment on how the speed of each block will change in the subsequent motion. For each block, give a reason for your answer. *(4 marks)*

January 2007

4 The diagram shows a block, of mass 13 kg, on a rough horizontal surface. It is attached by a string that passes over a smooth peg to a sphere of mass 7 kg, as shown in the diagram.



The system is released from rest, and after 4 seconds the block and the sphere both have speed $6\,\text{m s}^{-1}$, and the block has **not** reached the peg.

(a) State **two** assumptions that you should make about the string in order to model the motion of the sphere and the block. *(2 marks)*

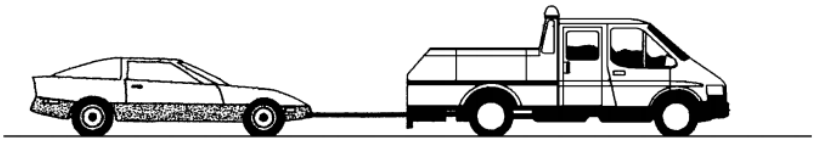
(b) Show that the acceleration of the sphere is $1.5\,\text{m s}^{-2}$. *(2 marks)*

(c) Find the tension in the string. *(3 marks)*

(d) Find the coefficient of friction between the block and the surface. *(6 marks)*

June 2007

4 A car, of mass 1200 kg, is connected by a tow rope to a truck, of mass 2800 kg. The truck tows the car in a straight line along a horizontal road. Assume that the tow rope is horizontal. A horizontal driving force of magnitude 3000 N acts on the truck. A horizontal resistance force of magnitude 800 N acts on the car. The car and truck accelerate at $0.4\,\text{m s}^{-2}$.



(a) Find the tension in the tow rope. *(3 marks)*

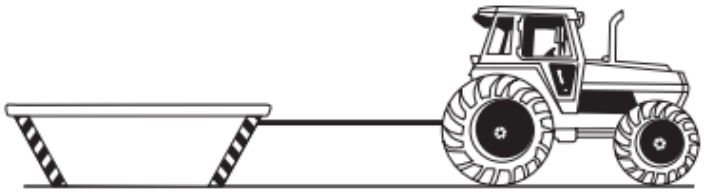
(b) Show that the magnitude of the horizontal resistance force acting on the truck is 600 N. *(4 marks)*

(c) In fact, the tow rope is **not** horizontal. Assume that the resistance forces and the driving force are unchanged.

Is the tension in the tow rope greater or less than in part (a)?

Explain why. *(2 marks)*

6 A tractor, of mass 4000 kg, is used to pull a skip, of mass 1000 kg, over a rough horizontal surface. The tractor is connected to the skip by a rope, which remains taut and horizontal throughout the motion, as shown in the diagram.



Assume that only **two** horizontal forces act on the tractor. One is a driving force, which has magnitude P newtons and acts in the direction of motion. The other is the tension in the rope.

The coefficient of friction between the skip and the ground is 0.4.

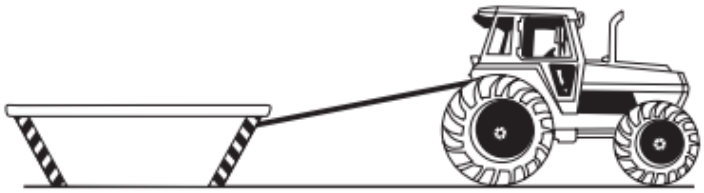
The tractor and the skip accelerate at $0.8\,\text{m}\,\text{s}^{-2}$.

(a) Show that the magnitude of the friction force acting on the skip is 3920 N. *(2 marks)*

(b) Show that $P = 7920$. *(3 marks)*

(c) Find the tension in the rope. *(3 marks)*

(d) Suppose that, during the motion, the rope is **not** horizontal, but inclined at a small angle to the horizontal, with the higher end of the rope attached to the tractor, as shown in the diagram.

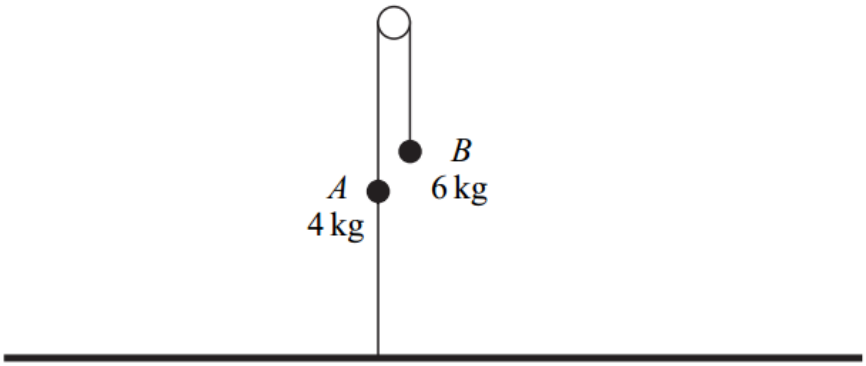


How would the magnitude of the friction force acting on the skip differ from that found in part (a)?

Explain why. *(2 marks)*

June 2008

3 Two particles, A and B, have masses 4 kg and 6 kg respectively. They are connected by a light inextensible string that passes over a smooth fixed peg. A second light inextensible string is attached to A. The other end of this string is attached to the ground directly below A. The system remains at rest, as shown in the diagram.



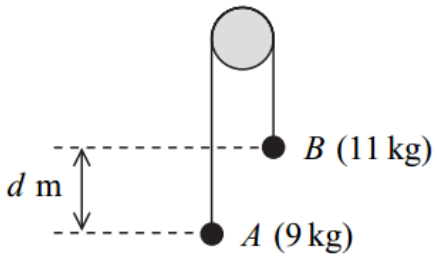
(a) (i) Write down the tension in the string connecting A and B. *(1 mark)*

(ii) Find the tension in the string connecting A to the ground. *(3 marks)*

(b) The string connecting particle A to the ground is cut. Find the acceleration of A after the string has been cut. *(5 marks)*

January 2009

4 Two particles, A and B, are connected by a string that passes over a fixed peg, as shown in the diagram. The mass of A is 9 kg and the mass of B is 11 kg.



The particles are released from rest in the position shown, where B is d metres higher than A. The motion of the particles is to be modelled using simple assumptions.

(a) State one assumption that should be made about the peg. *(1 mark)*

(b) State two assumptions that should be made about the string. *(2 marks)*

(c) By forming an equation of motion for each of the particles A and B, show that the acceleration of each particle has magnitude $0.98\,\text{m}\,\text{s}^{-2}$. *(5 marks)*

(d) When the particles have been moving for 0.5 seconds, they are at the same level.

(i) Find the speed of the particles at this time. *(2 marks)*

(ii) Find d. *(4 marks)*

5 A block, of mass 14 kg, is held at rest on a rough horizontal surface. The coefficient of friction between the block and the surface is 0.25. A light inextensible string, which passes over a fixed smooth peg, is attached to the block. The other end of the string is attached to a particle, of mass 6 kg, which is hanging at rest.

The block is released and begins to accelerate.

(a) Find the magnitude of the friction force acting on the block. *(3 marks)*

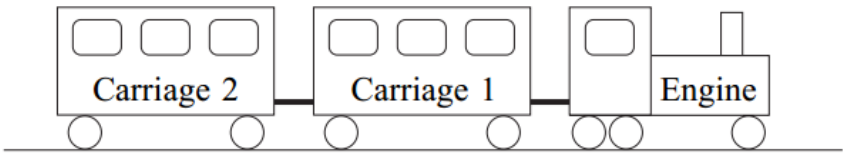
(b) By forming two equations of motion, one for the block and one for the particle, show that the magnitude of the acceleration of the block and the particle is $1.225\,\text{m}\,\text{s}^{-2}$. *(5 marks)*

(c) Find the tension in the string. *(2 marks)*

(d) When the block is released, it is 0.8 metres from the peg. Find the speed of the block when it hits the peg. *(3 marks)*

(e) When the block reaches the peg, the string breaks and the particle falls a further 0.5 metres to the ground. Find the speed of the particle when it hits the ground. *(3 marks)*

6 A small train at an amusement park consists of an engine and two carriages connected to each other by light horizontal rods, as shown in the diagram.



The engine has mass 2000 kg and each carriage has mass 500 kg.

The train moves along a straight horizontal track. A resistance force of magnitude 400 newtons acts on the engine, and resistance forces of magnitude 300 newtons act on each carriage. The train is accelerating at $0.5\,\text{m}\,\text{s}^{-2}$.

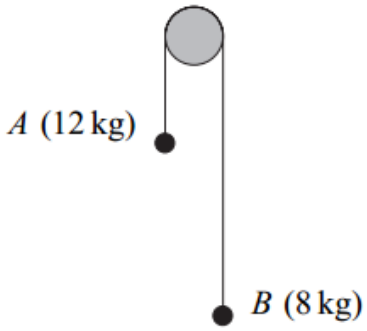
(a) Draw a diagram to show the **horizontal** forces acting on Carriage 2. *(1 mark)*

(b) Show that the magnitude of the force that the rod exerts on Carriage 2 is 550 newtons. *(2 marks)*

(c) Find the magnitude of the force that the rod attached to the engine exerts on Carriage 1. *(3 marks)*

(d) A forward driving force of magnitude P newtons acts on the engine. Find P. *(3 marks)*

6 Two particles, A and B, have masses 12 kg and 8 kg respectively. They are connected by a light inextensible string that passes over a smooth fixed peg, as shown in the diagram.



The particles are released from rest and move vertically. Assume that there is no air resistance.

(a) By forming two equations of motion, show that the magnitude of the acceleration of each particle is $1.96\,\text{m}\,\text{s}^{-2}$. *(5 marks)*

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

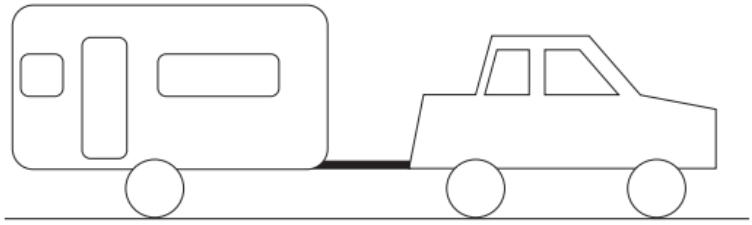
(c) After the particles have been moving for 2 seconds, both particles are at a height of 4 metres above a horizontal surface. When the particles are in this position, the string breaks.

(i) Find the speed of particle A when the string breaks. *(2 marks)*

(ii) Find the speed of particle A when it hits the surface. *(3 marks)*

(iii) Find the time that it takes for particle B to reach the surface after the string breaks. Assume that particle B does not hit the peg. *(5 marks)*

3 A car, of mass 1200 kg, tows a caravan, of mass 1000 kg, along a straight horizontal road. The caravan is attached to the car by a horizontal tow bar, as shown in the diagram.



Assume that a constant resistance force of magnitude 200 newtons acts on the car and a constant resistance force of magnitude 300 newtons acts on the caravan.
A constant driving force of magnitude P newtons acts on the car in the direction of motion. The car and caravan accelerate at $0.8\,\text{m}\,\text{s}^{-2}$.

(a) (i) Find P. *(3 marks)*

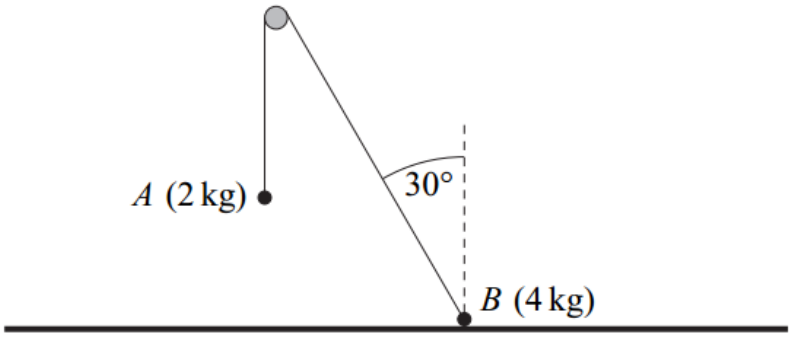
(ii) Find the magnitude of the force in the tow bar that connects the car to the caravan. *(3 marks)*

(b) (i) Find the time that it takes for the speed of the car and caravan to increase from $7\,\text{m}\,\text{s}^{-1}$ to $15\,\text{m}\,\text{s}^{-1}$. *(3 marks)*

(ii) Find the distance that they travel in this time. *(3 marks)*

(c) Explain why the assumption that the resistance forces are constant is unrealistic. *(1 mark)*

6 Two particles, A and B, are connected by a light inextensible string which passes over a smooth peg. Particle A has mass 2 kg and particle B has mass 4 kg. Particle A hangs freely with the string vertical. Particle B is at rest in equilibrium on a rough horizontal surface with the string at an angle of 30° to the vertical. The particles, peg and string are shown in the diagram.



(a) By considering particle A, find the tension in the string. *(2 marks)*

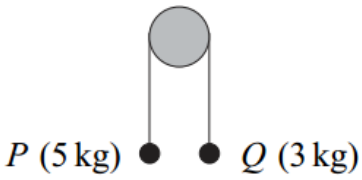
(b) Draw a diagram to show the forces acting on particle B. *(2 marks)*

(c) Show that the magnitude of the normal reaction force acting on particle B is 22.2 newtons, correct to three significant figures. *(3 marks)*

(d) Find the least possible value of the coefficient of friction between particle B and the surface. *(4 marks)*

June 2011

5 Two particles, P and Q, are connected by a string that passes over a fixed smooth peg, as shown in the diagram. The mass of P is 5 kg and the mass of Q is 3 kg.



The particles are released from rest in the position shown.

(a) By forming an equation of motion for each particle, show that the magnitude of the acceleration of each particle is 2.45 m s^{-2}. *(5 marks)*

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

(c) State **two** modelling assumptions that you have made about the string. *(2 marks)*

(d) Particle P hits the floor when it has moved 0.196 metres and Q has not reached the peg.

(i) Find the time that it takes P to reach the floor. *(3 marks)*

(ii) Find the speed of P when it hits the floor. *(2 marks)*

January 2012

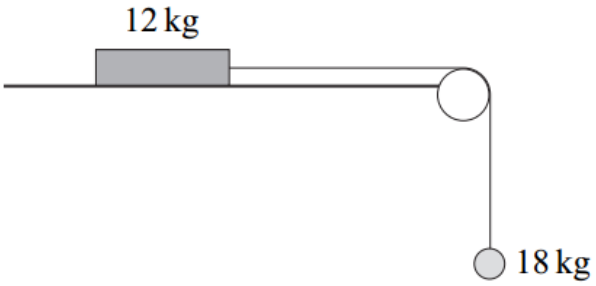
5 A car, of mass 1200 kg, tows a caravan, of mass 1000 kg, along a straight horizontal road. The caravan is attached to the car by a horizontal towbar. A resistance force of magnitude R newtons acts on the car and a resistance force of magnitude $2R$ newtons acts on the caravan. The car and caravan accelerate at a constant $1.6\,\text{m}\,\text{s}^{-2}$ when a driving force of magnitude 4720 newtons acts on the car.

(a) Find R. *(4 marks)*

(b) Find the tension in the towbar. *(3 marks)*

June 2012

5 A block, of mass 12 kg, lies on a horizontal surface. The block is attached to a particle, of mass 18 kg, by a light inextensible string which passes over a smooth fixed peg. Initially, the block is held at rest so that the string supports the particle, as shown in the diagram.



The block is then released.

(a) Assuming that the surface is smooth, use two equations of motion to find the magnitude of the acceleration of the block and particle. *(4 marks)*

(b) In reality, the surface is rough and the acceleration of the block is $3\,\text{m}\,\text{s}^{-2}$.

(i) Find the tension in the string. *(3 marks)*

(ii) Calculate the magnitude of the normal reaction force acting on the block. *(1 mark)*

(iii) Find the coefficient of friction between the block and the surface. *(5 marks)*

(c) State two modelling assumptions, other than those given, that you have made in answering this question. *(2 marks)*

January 2013

4 A tractor, of mass 3500 kg, is used to tow a trailer, of mass 2400 kg, across a horizontal field. The trailer is connected to the tractor by a horizontal tow bar. As they move, a constant resistance force of 800 newtons acts on the trailer and a constant resistance force of R newtons acts on the tractor. A forward driving force of 2500 newtons acts on the tractor. The trailer and tractor accelerate at $0.2\,\text{m}\,\text{s}^{-2}$.

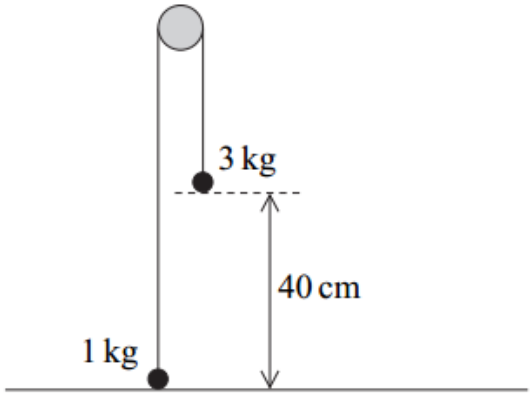
(a) Find R. *(3 marks)*

(b) Find the magnitude of the force that the tow bar exerts on the trailer. *(3 marks)*

(c) State the magnitude of the force that the tow bar exerts on the tractor. *(1 mark)*

June 2013

5 Two particles are connected by a light inextensible string that passes over a smooth peg. The particles have masses of 3 kg and 1 kg. The 1 kg particle is pulled down to ground level, where it is 40 cm below the level of the 3 kg particle, as shown in the diagram.



The particles are released from rest with the string vertical above each particle. Assume that no resistance forces act on the particles as they move.

(a) By forming two equations of motion, one for each particle, find the magnitude of the acceleration of the particles after they have been released but before the 3 kg particle hits the ground. *(5 marks)*

(b) Find the speed of the 1 kg particle when the 3 kg particle hits the ground. *(2 marks)*

(c) After the 3 kg particle has hit the ground, the 1 kg particle continues to move and the string is now slack. Find the maximum height above ground level reached by the 1 kg particle. *(3 marks)*

(d) If a constant air resistance force also acts on the particles as they move, explain how this would change your answer for the acceleration in part **(a)**. Give a reason for your answer. *(2 marks)*