adamjee maths

A-LEVEL MATHS / EDEXCEL / FREE RESOURCES

Forces and Newtonâ€™s laws

Question paper

20 questions

Exam questions and marking instructions remain credited to their board.

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1. A car moves in a straight line along a horizontal road with constant acceleration $2\,\text{m s}^{-2}$

The car is moving with speed $15\,\text{m s}^{-1}$ in the direction of the acceleration when it passes a signpost on the road.

The car is modelled as a particle.

(a) Use the model to find the speed of the car 4 s after passing the signpost.

(2)

Figure 1 below shows the horizontal forces acting on the car.

Given that

- the car has mass 800 kg
- the driving force of the engine has magnitude D newtons
- the resistance to the motion of the car has magnitude 400 N
- the acceleration of the car is $2\,\text{m s}^{-2}$ in the direction of the driving force

(b) use the model to find the value of D.

(2)

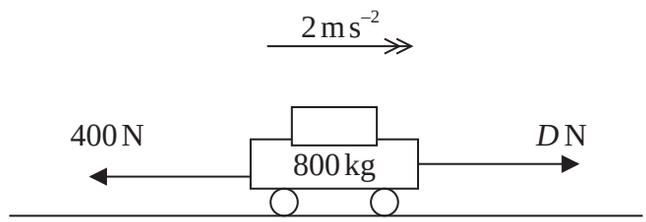


Figure 1

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Question 1 continued

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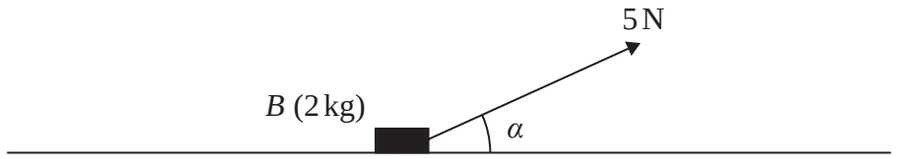


Figure 2

A small box B of mass 2 kg is dragged in a straight line, along a **rough** horizontal plane, at a **constant speed** by a force of magnitude 5 N.

The line of action of the force makes an angle α with the plane, where $\sin\alpha = \frac{3}{5}$, as shown in Figure 2.

(a) Show that the magnitude of the normal reaction of the plane on the box is 16.6 N.

(3)

At the instant when B is at the point O on the plane, the force of magnitude 5 N is removed.

(b) Describe the motion of the box after the force of magnitude 5 N is removed.

(1)

(c) Find the magnitude of the normal reaction of the plane on the box after the force of magnitude 5 N is removed.

(1)

Given that after the force of magnitude 5 N is removed

- the box is modelled as a particle
- air resistance is modelled as being negligible
- the coefficient of friction between the box and the plane is modelled as 0.2
- the speed of the box as it passes through O is $4\,\text{m s}^{-1}$
- the box comes to rest at the point X on the plane

(d) use the model to find the length OX.

(4)

(e) State one limitation of the model, apart from ignoring air resistance, that could affect your answer to part (d).

(1)

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Question 2 continued

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Question 2 continued

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3. [*In this question,* **i** *and* **j** *are horizontal unit vectors due east and due north respectively.*]

A particle P of mass 0.5 kg moves with constant acceleration $(2\mathbf{i} - 2.4\mathbf{j})\,\text{m s}^{-2}$ on a smooth horizontal plane under the action of a constant horizontal force **F** N.

(a) Find **F** in terms of **i** and **j**.

(1)

At time $t = 0$, P is moving with velocity $(-7\mathbf{i} + 7.8\mathbf{j})\,\text{m s}^{-1}$

(b) Find the velocity of P at time $t = 2$ seconds.

(2)

(c) Find the direction of motion of P at time $t = 2$ seconds, giving your answer as a bearing in degrees.

(3)

At time $t = 0$, P passes through the point O.

At time $t = 5$ seconds, P passes through the point A.

(d) Find $\overrightarrow{OA}$ in terms of **i** and **j**.

(2)

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4. [*In this question, position vectors are given relative to a fixed origin O.*]

At time t seconds, where $t > 0$, the position vector of a particle P is $\mathbf{r}$ metres where

$$\mathbf{r} = 4t^{\frac{3}{2}}\mathbf{i} - t^2\mathbf{j}$$

(a) Find the position vector of P at $t = 4$

(1)

(b) Find the exact distance of P from O at $t = 4$

(2)

(c) Find an expression for the velocity of P at time t seconds, where $t > 0$, giving your answer in terms of t, $\mathbf{i}$ and $\mathbf{j}$

(2)

At $t = T$, the acceleration of P is in a direction that is perpendicular to the line with equation $y = \frac{1}{3}x$

(d) Find the value of T.

(4)

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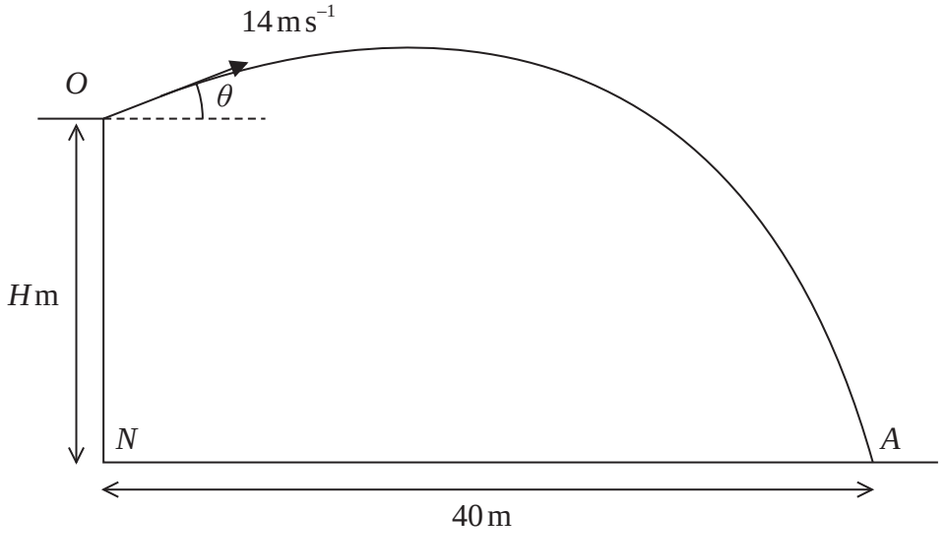


Figure 3

A small stone is projected with speed $14\,\text{m s}^{-1}$ from a point O on the top of a cliff. The point O is H metres vertically above the point N.

Point N is on horizontal ground.

The stone is projected at an angle θ above the horizontal, where $\tan\theta = \frac{1}{2}$

The stone strikes the horizontal ground at the point A, where $NA = 40\,\text{m}$, as shown in Figure 3.

The stone is modelled as a particle moving freely under gravity.

Using this model, find

(a) the value of H

(5)

(b) the maximum height of the stone above the horizontal ground.

(3)

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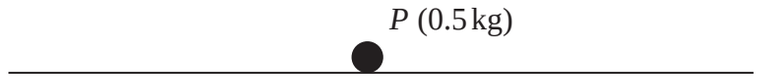


Figure 1

Figure 1 shows a particle P of mass 0.5 kg at rest on a rough horizontal plane.

(a) Find the magnitude of the normal reaction of the plane on P.

(1)

The coefficient of friction between P and the plane is $\frac{2}{7}$

A horizontal force of magnitude X newtons is applied to P.

Given that P is now in limiting equilibrium,

(b) find the value of X.

(2)

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Question 1 continued

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4. **In this question you must show all stages of your working.**

Solutions relying entirely on calculator technology are not acceptable.

[*In this question,* **i** *is a unit vector due east and* **j** *is a unit vector due north. Position vectors are given relative to a fixed origin O.*]

At time t seconds, $t \geqslant 1$, the position vector of a particle P is **r** metres, where

$$\mathbf{r} = ct^{\frac{1}{2}}\mathbf{i} - \frac{3}{8}t^2\mathbf{j}$$

and c is a constant.

When $t = 4$, the bearing of P from O is 135°

(a) Show that $c = 3$

(3)

(b) Find the speed of P when $t = 4$

(4)

When $t = T$, P is accelerating in the direction of $(-\mathbf{i} - 27\mathbf{j})$.

(c) Find the value of T.

(4)

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Question 4 continued

(Total for Question 4 is 11 marks)

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2.



Figure 1

A particle P has mass 5 kg.

The particle is pulled along a rough horizontal plane by a horizontal force of magnitude 28 N.

The only resistance to motion is a frictional force of magnitude F newtons, as shown in Figure 1.

(a) Find the magnitude of the normal reaction of the plane on P

(1)

The particle is accelerating along the plane at $1.4\,\text{m}\,\text{s}^{-2}$

(b) Find the value of F

(2)

The coefficient of friction between P and the plane is μ

(c) Find the value of μ, giving your answer to 2 significant figures.

(1)

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Question 2 continued

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4. [*In this question,* **i** *and* **j** *are horizontal unit vectors and position vectors are given relative to a fixed origin O*]

A particle P is moving on a smooth horizontal plane.

The particle has constant acceleration $(2.4\mathbf{i} + \mathbf{j})\,\text{m s}^{-2}$

At time $t = 0$, P passes through the point A.

At time $t = 5\,\text{s}$, P passes through the point B.

The velocity of P as it passes through A is $(-16\mathbf{i} - 3\mathbf{j})\,\text{m s}^{-1}$

(a) Find the speed of P as it passes through B.

(4)

The position vector of A is $(44\mathbf{i} - 10\mathbf{j})\,\text{m}$.

At time $t = T$ seconds, where $T > 5$, P passes through the point C.

The position vector of C is $(4\mathbf{i} + c\mathbf{j})\,\text{m}$.

(b) Find the value of T.

(3)

(c) Find the value of c.

(3)

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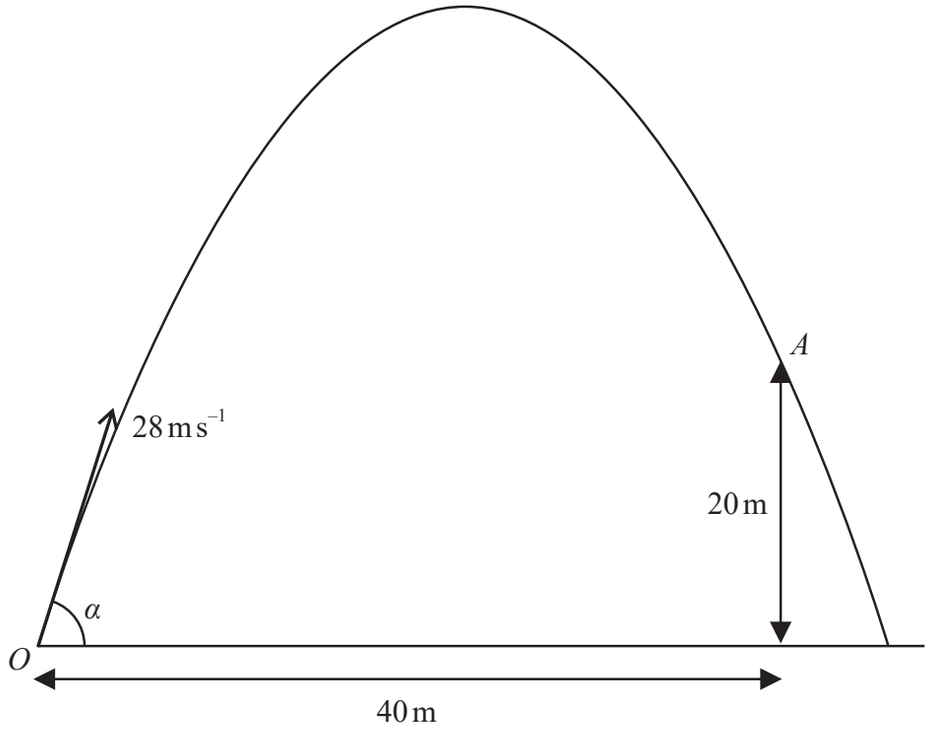


Figure 2

A small ball is projected with speed $28\,\text{m}\,\text{s}^{-1}$ from a point O on horizontal ground.

After moving for T seconds, the ball passes through the point A.

The point A is 40 m horizontally and 20 m vertically from the point O, as shown in Figure 2.

The motion of the ball from O to A is modelled as that of a particle moving freely under gravity.

Given that the ball is projected at an angle α to the ground, use the model to

(a) show that $T = \dfrac{10}{7\cos\alpha}$

(2)

(b) show that $\tan^2\alpha - 4\tan\alpha + 3 = 0$

(5)

(c) find the greatest possible height, in metres, of the ball above the ground as the ball moves from O to A.

(3)

The model does not include air resistance.

(d) State one other limitation of the model.

(1)

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Question 5 continued

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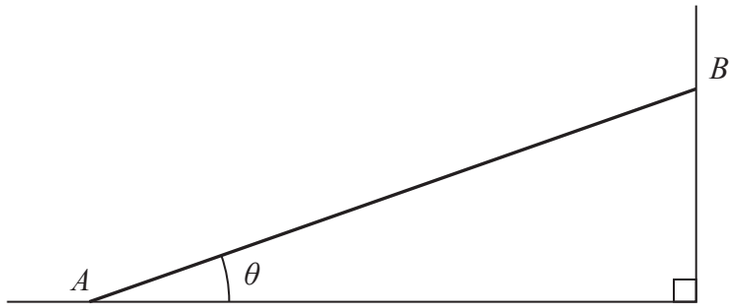


Figure 3

A rod AB has mass M and length $2a$.

The rod has its end A on rough horizontal ground and its end B against a smooth vertical wall.

The rod makes an angle θ with the ground, as shown in Figure 3.

The rod is at rest in limiting equilibrium.

(a) State the direction (left or right on Figure 3 above) of the frictional force acting on the rod at A. **Give a reason for your answer.**

(1)

The magnitude of the normal reaction of the wall on the rod at B is S.

In an initial model, the rod is modelled as being **uniform**.

Use this initial model to answer parts (b), (c) and (d).

(b) By taking moments about A, show that

$$S = \frac{1}{2} Mg \cot\theta$$

(3)

The coefficient of friction between the rod and the ground is μ

Given that $\tan\theta = \frac{3}{4}$

(c) find the value of μ

(5)

(d) find, in terms of M and g, the magnitude of the resultant force acting on the rod at A.

(3)

In a new model, the rod is modelled as being **non-uniform**, with its centre of mass closer to B than it is to A.

A new value for S is calculated using this new model, with $\tan\theta = \frac{3}{4}$

(e) State whether this new value for S is larger, smaller or equal to the value that S would take using the initial model. **Give a reason for your answer.**

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Question 6 continued

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Question 6 continued

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TOTAL FOR MECHANICS IS 50 MARKS

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3. [*In this question,* **i** *and* **j** *are horizontal unit vectors.*]

A particle P of mass 4 kg is at rest at the point A on a smooth horizontal plane.

At time $t = 0$, two forces, $\mathbf{F}_1 = (4\mathbf{i} - \mathbf{j})$ N and $\mathbf{F}_2 = (\lambda\mathbf{i} + \mu\mathbf{j})$ N, where λ and μ are constants, are applied to P

Given that P moves in the direction of the vector $(3\mathbf{i} + \mathbf{j})$

(a) show that

$$\lambda - 3\mu + 7 = 0$$

(4)

At time $t = 4$ seconds, P passes through the point B.

Given that $\lambda = 2$

(b) find the length of AB.

(5)

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Question 3 continued

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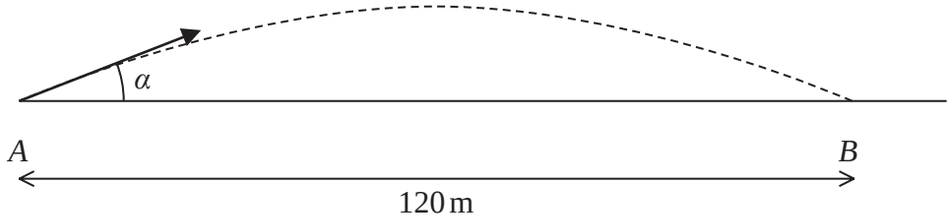


Figure 3

A golf ball is at rest at the point A on horizontal ground.

The ball is hit and initially moves at an angle α to the ground.

The ball first hits the ground at the point B, where $AB = 120\,\text{m}$, as shown in Figure 3.

The motion of the ball is modelled as that of a particle, moving freely under gravity, whose initial speed is $U\,\text{m s}^{-1}$

Using this model,

(a) show that $U^2 \sin\alpha\cos\alpha = 588$

(6)

The ball reaches a maximum height of 10 m above the ground.

(b) Show that $U^2 = 1960$

(4)

In a refinement to the model, the effect of air resistance is included.

The motion of the ball, from A to B, is now modelled as that of a particle whose initial speed is $V\,\text{m s}^{-1}$

This refined model is used to calculate a value for V

(c) State which is greater, U or V, giving a reason for your answer.

(1)

(d) State one further refinement to the model that would make the model more realistic.

(1)

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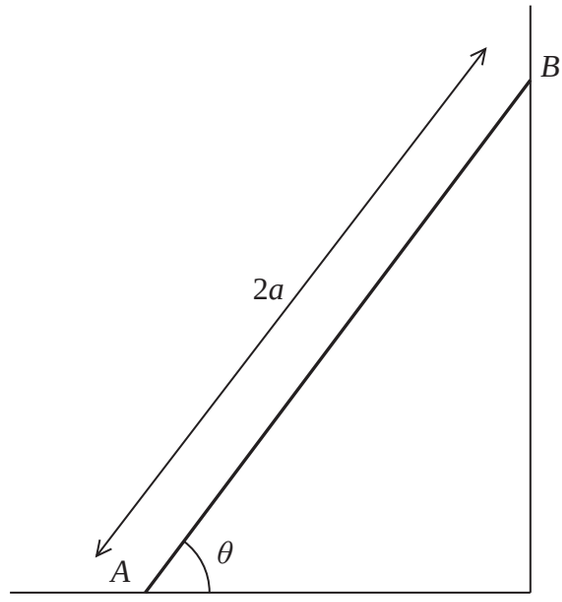


Figure 2

A beam AB has mass m and length $2a$.

The beam rests in equilibrium with A on rough horizontal ground and with B against a smooth vertical wall.

The beam is inclined to the horizontal at an angle θ, as shown in Figure 2.

The coefficient of friction between the beam and the ground is μ

The beam is modelled as a uniform rod resting in a vertical plane that is perpendicular to the wall.

Using the model,

(a) show that $\mu \geqslant \frac{1}{2}\cot\theta$

(5)

A horizontal force of magnitude kmg, where k is a constant, is now applied to the beam at A.

This force acts in a direction that is perpendicular to the wall and towards the wall.

Given that $\tan\theta = \frac{5}{4}$, $\mu = \frac{1}{2}$ and the beam is now in limiting equilibrium,

(b) use the model to find the value of k.

(5)

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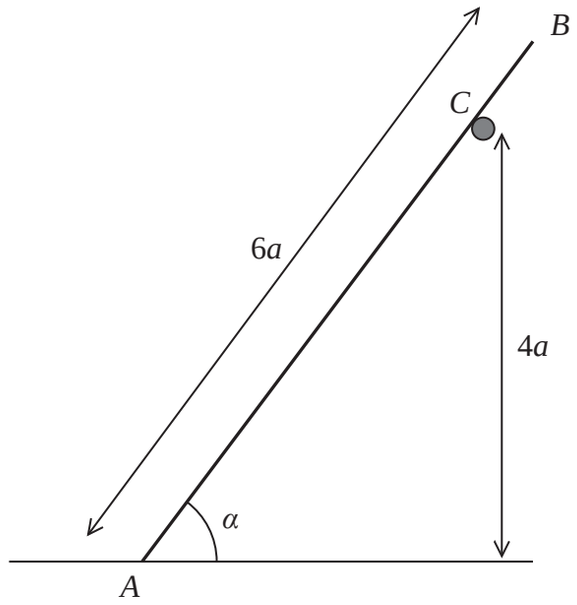


Figure 1

A ladder AB has mass M and length $6a$.

The end A of the ladder is on rough horizontal ground.

The ladder rests against a fixed smooth horizontal rail at the point C.

The point C is at a vertical height $4a$ above the ground.

The vertical plane containing AB is perpendicular to the rail.

The ladder is inclined to the horizontal at an angle α, where $\sin\alpha = \frac{4}{5}$, as shown in Figure 1.

The coefficient of friction between the ladder and the ground is μ.

The ladder rests in limiting equilibrium.

The ladder is modelled as a uniform rod.

Using the model,

(a) show that the magnitude of the force exerted on the ladder by the rail at C is $\frac{9Mg}{25}$

(3)

(b) Hence, or otherwise, find the value of μ.

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Question 4 continued

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Question 4 continued

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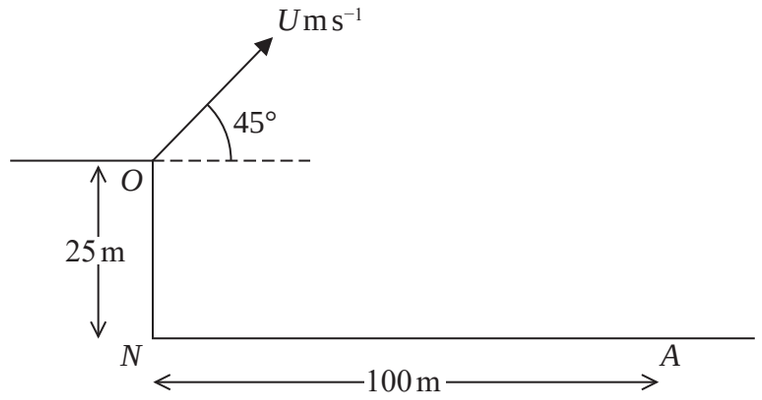


Figure 2

A small ball is projected with speed U m s^{-1} from a point O at the top of a vertical cliff.

The point O is 25 m vertically above the point N which is on horizontal ground.

The ball is projected at an angle of 45° above the horizontal.

The ball hits the ground at a point A, where $AN = 100$ m, as shown in Figure 2.

The motion of the ball is modelled as that of a particle moving freely under gravity.

Using this initial model,

(a) show that $U = 28$

(6)

(b) find the greatest height of the ball above the horizontal ground NA.

(3)

In a refinement to the model of the motion of the ball from O to A, the effect of air resistance is included.

This refined model is used to find a new value of U.

(c) How would this new value of U compare with 28, the value given in part (a)?

(1)

(d) State one further refinement to the model that would make the model more realistic.

(1)

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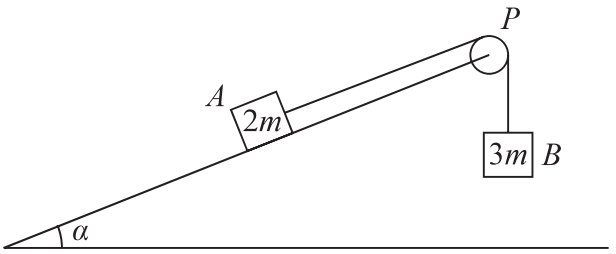


Figure 1

Two blocks, A and B, of masses $2m$ and $3m$ respectively, are attached to the ends of a light string.

Initially A is held at rest on a fixed rough plane.

The plane is inclined at angle α to the horizontal ground, where $\tan\alpha = \frac{5}{12}$

The string passes over a small smooth pulley, P, fixed at the top of the plane.

The part of the string from A to P is parallel to a line of greatest slope of the plane. Block B hangs freely below P, as shown in Figure 1.

The coefficient of friction between A and the plane is $\frac{2}{3}$

The blocks are released from rest with the string taut and A moves up the plane.

The tension in the string immediately after the blocks are released is T.

The blocks are modelled as particles and the string is modelled as being inextensible.

(a) Show that $T = \frac{12mg}{5}$

(8)

After B reaches the ground, A continues to move up the plane until it comes to rest before reaching P.

(b) Determine whether A will remain at rest, carefully justifying your answer.

(2)

(c) Suggest two refinements to the model that would make it more realistic.

(2)

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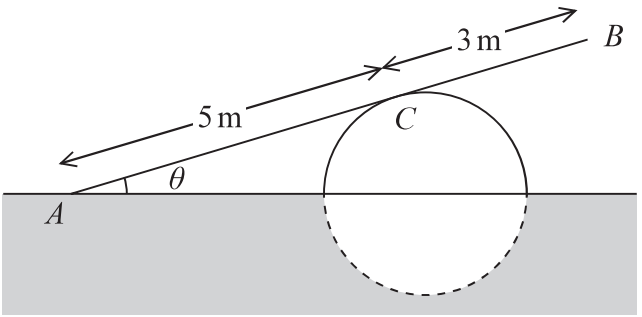


Figure 2

A ramp, AB, of length 8 m and mass 20 kg, rests in equilibrium with the end A on rough horizontal ground.

The ramp rests on a smooth solid cylindrical drum which is partly under the ground. The drum is fixed with its axis at the same horizontal level as A.

The point of contact between the ramp and the drum is C, where $AC = 5$ m, as shown in Figure 2.

The ramp is resting in a vertical plane which is perpendicular to the axis of the drum, at an angle θ to the horizontal, where $\tan\theta = \frac{7}{24}$

The ramp is modelled as a uniform rod.

(a) Explain why the reaction from the drum on the ramp at point C acts in a direction which is perpendicular to the ramp.

(1)

(b) Find the magnitude of the resultant force acting on the ramp at A.

(9)

The ramp is still in equilibrium in the position shown in Figure 2 but the ramp is not now modelled as being uniform.

Given that the centre of mass of the ramp is assumed to be closer to A than to B,

(c) state how this would affect the magnitude of the normal reaction between the ramp and the drum at C.

(1)

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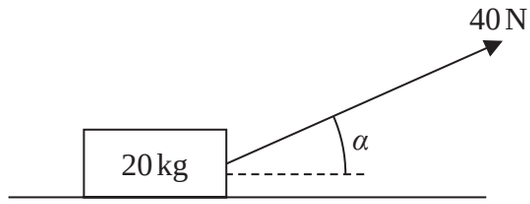


Figure 1

A wooden crate of mass 20 kg is pulled in a straight line along a rough horizontal floor using a handle attached to the crate.

The handle is inclined at an angle α to the floor, as shown in Figure 1, where $\tan\alpha = \frac{3}{4}$

The tension in the handle is 40 N.
The coefficient of friction between the crate and the floor is 0.14
The crate is modelled as a particle and the handle is modelled as a light rod.

Using the model,

(a) find the acceleration of the crate.

(6)

The crate is now pushed along the same floor using the handle. The handle is again inclined at the same angle α to the floor, and the thrust in the handle is 40 N as shown in Figure 2 below.



Figure 2

(b) Explain briefly why the acceleration of the crate would now be less than the acceleration of the crate found in part (a).

(2)

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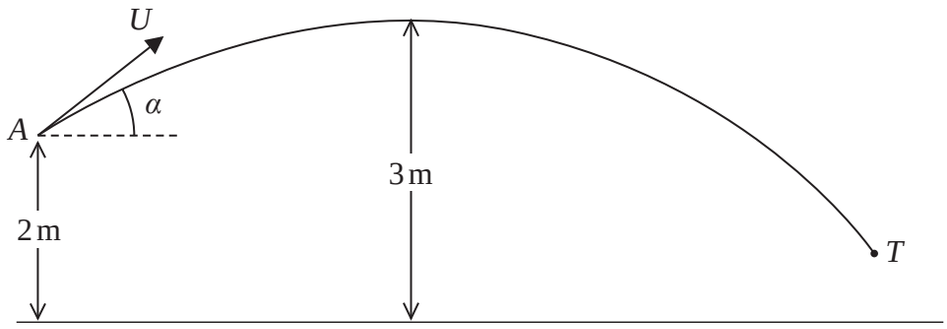


Figure 4

A boy throws a ball at a target. At the instant when the ball leaves the boy's hand at the point *A*, the ball is 2 m above horizontal ground and is moving with speed U at an angle α above the horizontal.

In the subsequent motion, the highest point reached by the ball is 3 m above the ground. The target is modelled as being the point *T*, as shown in Figure 4.
The ball is modelled as a particle moving freely under gravity.

Using the model,

(a) show that $U^2 = \dfrac{2g}{\sin^2 \alpha}$.

(2)

The point *T* is at a horizontal distance of 20 m from *A* and is at a height of 0.75 m above the ground. The ball reaches *T* without hitting the ground.

(b) Find the size of the angle α

(9)

(c) State one limitation of the model that could affect your answer to part (b).

(1)

(d) Find the time taken for the ball to travel from *A* to *T*.

(3)

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TOTAL FOR SECTION B IS 50 MARKS

TOTAL FOR PAPER IS 100 MARKS

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