Dynamics and inclined planes

98 marks

Hints online, answers free with an account: mathswariz.uk/worksheets/a-level-mechanics-year-2-dynamics-inclined-planes/

Date

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A Do Now

Quick questions to start. Some use earlier lessons; some set a slip that costs marks.

A1 Needed today [2 marks]

A particle of mass $6\ \text{kg}$ rests on a plane inclined at 32° to the horizontal. Find the component of its weight parallel to the plane and the component perpendicular to the plane.

Answer .....

A2 Needed today [2 marks]

A particle starts from rest and moves with constant acceleration. It travels $9\ \text{m}$ in $3\ \text{s}$. Find its acceleration and its speed after $3\ \text{s}$.

Answer .....

A3 Needed today [2 marks]

An angle α is acute and $\tan\alpha = \dfrac{7}{24}$. Find the exact values of $\sin\alpha$ and $\cos\alpha$.

Answer .....

A4 Common slip [3 marks]

A box of mass $5\ \text{kg}$ is at rest on rough horizontal ground. The coefficient of friction is 0.4. A horizontal force of $12\ \text{N}$ acts on the box and it does not move. Jo says the friction is $0.4 \times 5g = 19.6\ \text{N}$. Find the friction and explain Jo's mistake.

Answer .....

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A5 Common slip [2 marks]

A particle is projected up the line of greatest slope of a rough plane. It comes to rest and then slides back down. State the direction of the friction (i) while it moves up the plane, (ii) while it slides down.

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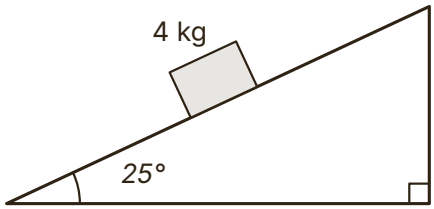
PART 1 Sliding down a rough slope

EXAMPLE 1 · I DO

A particle of mass $4\ \text{kg}$ is released from rest on a rough plane inclined at 25° to the horizontal. The coefficient of friction between the particle and the plane is 0.2. Find the acceleration of the particle and its speed after it has moved $3\ \text{m}$.



Hint Resolve perpendicular to the plane first to find R. The particle moves, so friction is limiting: $F = \mu R$, acting up the plane.

YOUR TURN · WE DO

B1 A particle of mass $2.5\ \text{kg}$ is released from rest on a rough plane inclined at α to the horizontal, where $\tan\alpha = \frac{5}{12}$. The coefficient of friction is 0.1. Find the acceleration of the particle and the distance it moves in the first $2.5\ \text{s}$. [4 marks]

Answer .....

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EXAMPLE 2 · I DO

A block of mass $3\ \text{kg}$ is released from rest on a rough plane inclined at 30° to the horizontal. After $2.5\ \text{s}$ its speed is $7\ \text{m s}^{-1}$. Find the coefficient of friction between the block and the plane.

Hint Find the acceleration from the motion first. Then write the equation of motion down the plane with $F = \mu R$ and solve for μ.

YOUR TURN · WE DO

B2 A block of mass $6\ \text{kg}$ is released from rest on a rough plane inclined at 40° to the horizontal. It slides $4\ \text{m}$ down the plane in $1.6\ \text{s}$. Find the coefficient of friction between the block and the plane. [4 marks]

Answer .....

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C1 A particle of mass $2\ \text{kg}$ slides down a rough plane inclined at 35° to the horizontal. The coefficient of friction is 0.3. Max writes "$F = 0.3 \times 2g = 5.88$, so $2g\sin 35^\circ - 5.88 = 2a$, $a = 2.68$." Explain his mistake and find the correct acceleration. [4 marks]

Answer .....

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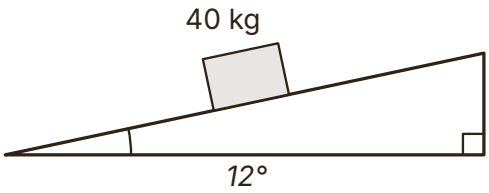
C2 A crate of mass $40\ \text{kg}$ is released from rest on a rough ramp inclined at 12° to the horizontal. It slides $3\ \text{m}$ down the ramp in $2.5\ \text{s}$. The crate is modelled as a particle. Find the coefficient of friction between the crate and the ramp. [4 marks]



Answer .....

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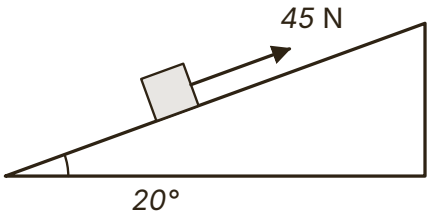
PART 2 A force acting up the slope

EXAMPLE 3 · I DO

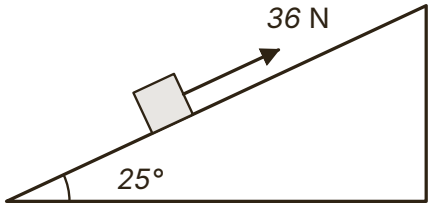
A box of mass $5\ \text{kg}$ is pulled up a rough plane inclined at $20°$ to the horizontal by a force of $45\ \text{N}$ acting parallel to a line of greatest slope. The coefficient of friction is 0.3. Find the acceleration of the box.



Hint The force is parallel to the plane, so $R = 5g\cos 20°$. The box moves up, so friction acts down the plane.

YOUR TURN · WE DO

B3 A block of mass $3\ \text{kg}$ is pulled up a rough plane inclined at $25°$ to the horizontal by a light rope parallel to a line of greatest slope. The tension in the rope is $36\ \text{N}$ and the coefficient of friction is 0.4. Find the acceleration of the block. [4 marks]



Answer .....

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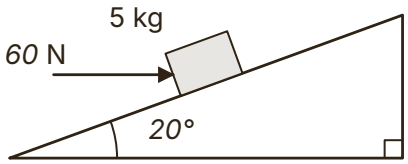
EXAMPLE 4 · I DO

A box of mass $5\ \text{kg}$ is pushed up a rough plane inclined at 20° to the horizontal by a horizontal force of magnitude $60\ \text{N}$. The force acts in the vertical plane containing a line of greatest slope. The coefficient of friction is 0.3. Find the acceleration of the box.



Hint Resolve the $60\ \text{N}$ force into a part along the plane and a part INTO the plane. The part into the plane adds to the normal reaction.

YOUR TURN · WE DO

B4 A box of mass $3\ \text{kg}$ is pushed up a rough plane inclined at α to the horizontal, where $\tan\alpha = \frac{3}{4}$, by a horizontal force of magnitude $45\ \text{N}$ in the vertical plane containing a line of greatest slope. The coefficient of friction is 0.25. Find the normal reaction and the acceleration of the box. [5 marks]

Answer .....

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C3 A box of mass $4\ \text{kg}$ is pushed up a rough plane inclined at 30° to the horizontal by a horizontal force of $50\ \text{N}$. The coefficient of friction is 0.2. Ravi writes "$R = 4g\cos 30^\circ = 33.9$" and gets $a = 4.23\ \text{m s}^{-2}$. Explain Ravi's mistake and find the correct acceleration. [5 marks]

Answer .....

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C4 A box of mass $10\ \text{kg}$ is on a rough plane inclined at $20°$ to the horizontal. The coefficient of friction is 0.6. A rope parallel to the line of greatest slope pulls up the plane with a force of $30\ \text{N}$. Leo writes "friction $= \mu R = 55.3\ \text{N}$ down the plane, so $30 - 10g\sin 20° - 55.3 = 10a$, $a = -5.88$, the box accelerates down." Explain the two errors in Leo's working. Find the size and direction of the friction. [5 marks]

Answer .....

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PART 3 Projected up a rough slope

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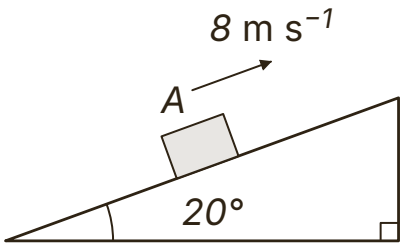
EXAMPLE 5 · I DO

A particle is projected up a line of greatest slope of a rough plane inclined at 20° to the horizontal. It starts from A with speed $8\ \mathrm{m\ s^{-1}}$. The coefficient of friction is 0.25. Find the distance it moves up the plane before coming to rest, and the time this takes. Show that it then slides back, and find its speed when it returns to A.



Hint Going up, friction acts DOWN the plane with the weight component. At rest, compare $mg\sin 20^\circ$ with $F_{\max} = \mu mg\cos 20^\circ$. Coming down, friction acts UP the plane: a different acceleration.

YOUR TURN · WE DO

B5 A particle of mass $2\ \mathrm{kg}$ is projected up a line of greatest slope of a rough plane inclined at 25° to the horizontal, from A with speed $10\ \mathrm{m\ s^{-1}}$. The coefficient of friction is 0.3. Find the distance it moves up the plane before coming to rest. Show that it slides back, and find its speed when it returns to A. [7 marks]

Answer .....

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C5 A particle is projected up a line of greatest slope of a rough plane inclined at 30° to the horizontal, with speed $6\ \mathrm{m\ s^{-1}}$. The coefficient of friction is 0.2. Ella says: "It goes up and comes back the same distance, so it returns to its starting point at $6\ \mathrm{m\ s^{-1}}$." Explain why Ella is wrong and find the speed with which it returns. [5 marks]

Answer .....

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C6 A particle is projected up a line of greatest slope of a rough plane inclined at 15° to the horizontal, with speed $5\ \text{m s}^{-1}$. The coefficient of friction is 0.5. Find the distance it moves before it comes to rest. Kim then writes "it slides down with $a = g(\sin 15^\circ - 0.5\cos 15^\circ) = -2.20\ \text{m s}^{-2}$". Explain what Kim's negative answer shows, and state what happens to the particle. [5 marks]

Answer .....

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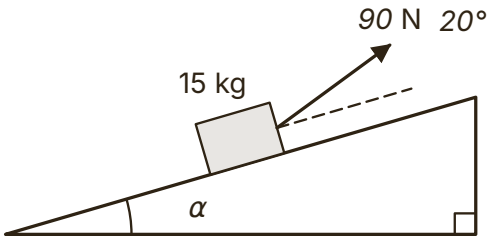
D1 A sledge of mass $15\ \text{kg}$ is pulled from rest up a rough slope by a rope. The slope is inclined at α to the horizontal, where $\tan\alpha = \frac{7}{24}$. The rope makes an angle of 20° with the line of greatest slope, and the tension in the rope is $90\ \text{N}$. The coefficient of friction between the sledge and the slope is 0.25. The sledge is modelled as a particle and the rope as light.

(a) Show that the normal reaction on the sledge is $110\ \text{N}$, to 3 significant figures. [3 marks]



Answer .....

(b) Find the acceleration of the sledge. [3 marks]

Answer .....

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(c) After $4\ \text{s}$ the rope breaks. Find the further distance the sledge moves up the slope. [4 marks]

Answer .....

(d) Determine whether the sledge slides back down the slope. If it does, find its acceleration. [3 marks]

Answer .....

Total for D1: 13 marks

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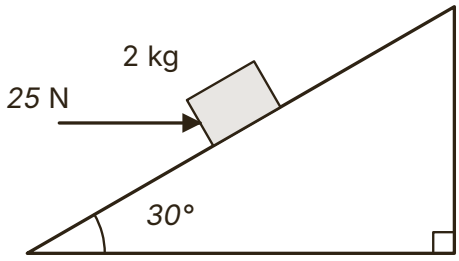
D2

A box of mass $2\ \text{kg}$ is on a rough plane inclined at $30°$ to the horizontal. The coefficient of friction is 0.25. The box is pushed from rest up the plane by a horizontal force of magnitude $25\ \text{N}$, acting in the vertical plane containing a line of greatest slope. After $3\ \text{s}$ the force is removed. Sam finds the friction while the force acts to be $7.37\ \text{N}$, then writes: "After the force is removed: $-2g\sin 30° - 7.37 = 2a$, so the deceleration is $8.58\ \text{m s}^{-2}$."

Sam has made an error in the second stage.

(a) Find the acceleration of the box while the force acts. [4 marks]



Answer .....

(b) Find the speed of the box when the force is removed. [2 marks]

Answer .....

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(c) Explain Sam's error. Find the distance the box moves up the plane after the force is removed. [4 marks]

Answer .....

(d) The box then slides back down the plane. Find its speed when it passes the point where the force was removed. [3 marks]

Answer .....

Total for D2: 13 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 A particle slides down a line of greatest slope of a rough plane inclined at 25° to the horizontal. It passes the points P, Q and R in that order, where $PQ = QR = 4\ \text{m}$. It takes $1.2\ \text{s}$ to move from P to Q and $0.8\ \text{s}$ to move from Q to R. The particle was released from rest at a point O on the same line, above P. Find the coefficient of friction between the particle and the plane, and the distance OP. [9 marks]

Answer .....

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Extension hints

Cover these with paper. Uncover one at a time.

E1

Hint 1 Call the speed at P u and the acceleration a. Use $s = ut + \frac{1}{2}at^2$ from P to Q, and again from P to R (8 m in 2 s).

Hint 2 Solve the two equations for u and a. Then resolve: friction acts up the plane, and the mass cancels in $mg\sin 25^\circ - \mu mg\cos 25^\circ = ma$.

Hint 3 From rest at O to P the acceleration is the same, so $u^2 = 2a \times OP$.

How did it go?

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

I can find the normal reaction and the friction on a body moving on a rough slope, including when a force acts at an angle.	○ ○ ○
I can write an equation of motion along the slope and use it with the constant acceleration formulae.	○ ○ ○
I can decide whether a body projected up a rough slope slides back, and find its speed when it returns.	○ ○ ○
I can find the coefficient of friction from information about the motion.	○ ○ ○

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