Friction

116 marks

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

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 $6\ \text{kg}$ is on a plane inclined at 28° to the horizontal. Find the components of its weight parallel to the plane and perpendicular to the plane.

Answer .....

A2 Common slip [2 marks]

A box of mass $10\ \text{kg}$ rests on a horizontal floor. A rope pulls on it with a force of $50\ \text{N}$ at 30° above the horizontal, and the box does not move. Find the normal reaction of the floor on the box.

Answer .....

A3 Needed today [2 marks]

A car moving at $15\ \text{m s}^{-1}$ decelerates uniformly and comes to rest in $25\ \text{m}$. Find its deceleration.

Answer .....

A4 Common slip [2 marks]

A trolley moves along a straight horizontal track at a constant speed of $3\ \text{m s}^{-1}$. A force of $30\ \text{N}$ pulls it forwards and a resistance $P\ \text{N}$ acts against the motion. Find P.

Answer .....

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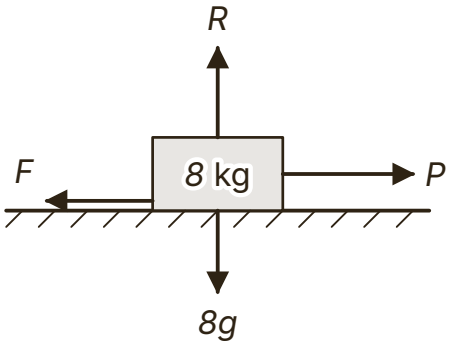
B Example, then your turn

A-Level

Your teacher works through each example with you. Then try the one beside it.

EXAMPLE 1

A block of mass $8\ \text{kg}$ is at rest on a rough horizontal floor. The coefficient of friction between the block and the floor is 0.35. A horizontal force of $P\ \text{N}$ is applied to the block. Find the friction force and the acceleration of the block (a) when $P = 20$ and (b) when $P = 35$.



Hint First find the greatest friction the floor can give, μR. Friction only reaches μR if the block moves or is about to move. Otherwise it is just large enough to stop the block moving.

B1 A crate of mass $12\ \text{kg}$ is at rest on a rough horizontal floor, with coefficient of friction 0.25. A horizontal force of $P\ \text{N}$ is applied. Find the friction force and the acceleration when P is (a) 25 and (b) 40. [4 marks]

Answer .....

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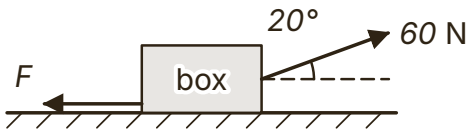
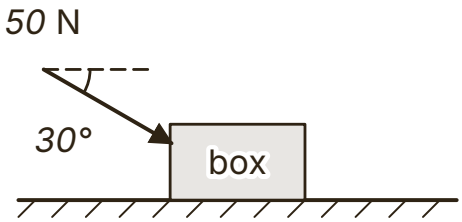
EXAMPLE 2

A box of mass $15\ \text{kg}$ is pulled along a rough horizontal floor by a rope inclined at $20°$ above the horizontal. The tension in the rope is $60\ \text{N}$ and the coefficient of friction is 0.3. Find the acceleration of the box.



Hint Resolve vertically first. The rope pulls partly upwards, so R is less than $15g$, and the friction is 0.3 of this smaller R.

B2 A box of mass $9\ \text{kg}$ is pushed along a rough horizontal floor by a force of $50\ \text{N}$ acting at $30°$ below the horizontal. The coefficient of friction is 0.2. Find the acceleration of the box. [5 marks]



Answer .....

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EXAMPLE 3

An ice hockey puck is hit across a horizontal sheet of ice with speed $8\ \mathrm{m\ s^{-1}}$. It slides in a straight line and comes to rest after $20\ \mathrm{m}$. Modelling the puck as a particle and the only resistance as friction, find the coefficient of friction between the puck and the ice.

Hint Find the deceleration from the suvat equations. Friction μmg is the only horizontal force, so $\mu mg = md$ and the mass cancels.

B3 A car travelling at $22\ \mathrm{m\ s^{-1}}$ on a horizontal road brakes so that its wheels lock. It skids in a straight line and stops in $3.5\ \mathrm{s}$. Modelling the car as a particle and the only resistance as friction, find the coefficient of friction between the tyres and the road. [4 marks]

Answer .....

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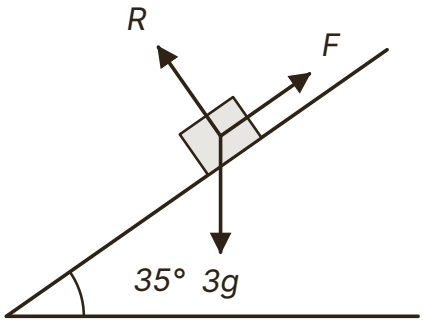
EXAMPLE 4

A particle of mass $3\ \text{kg}$ slides down a rough plane inclined at $35°$ to the horizontal with acceleration $2.5\ \text{m s}^{-2}$. Find the coefficient of friction between the particle and the plane.



Hint The particle moves down the plane, so friction acts up the plane and equals μR. Find R by resolving perpendicular to the plane.

B4 A particle of mass $1.5\ \text{kg}$ is released from rest on a rough plane inclined at $25°$ to the horizontal. The coefficient of friction is 0.2. Find the acceleration of the particle and its speed after it has slid $3\ \text{m}$. [5 marks]

Answer .....

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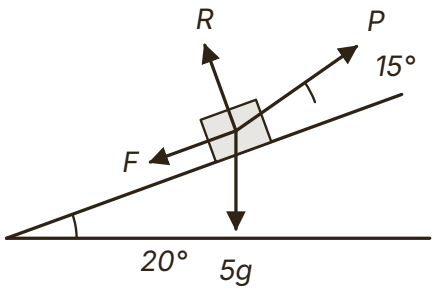
EXAMPLE 5

A particle of mass $5\ \text{kg}$ is pulled up a rough plane inclined at $20°$ to the horizontal by a force of $P\ \text{N}$ acting at $15°$ above the line of greatest slope. The coefficient of friction is 0.3 and the particle accelerates up the plane at $0.6\ \text{m s}^{-2}$. Find P.



Hint R depends on P, because P has a component $P\sin 15°$ away from the plane. Write R in terms of P, then put $F = 0.3R$ into the equation of motion up the plane.

B5 A particle of mass $4\ \text{kg}$ is pulled up a rough plane inclined at $30°$ to the horizontal by a force of $50\ \text{N}$ acting at $20°$ above the line of greatest slope. The coefficient of friction is 0.25. Find the normal reaction and the acceleration of the particle. [5 marks]

Answer .....

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C1 A crate of mass $20\ \text{kg}$ rests on a rough horizontal floor. The coefficient of friction is 0.5. A horizontal force of $60\ \text{N}$ is applied to the crate. Tom writes "friction is $\mu R = 0.5 \times 20g = 98\ \text{N}$, which is more than $60\ \text{N}$, so the crate accelerates backwards". Explain Tom's mistake, and find the friction force and the acceleration of the crate. [4 marks]

Answer .....

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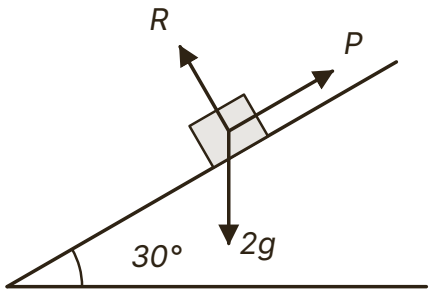
C2 A particle of mass $2\ \text{kg}$ is sliding down a rough plane inclined at $30°$ to the horizontal. The coefficient of friction is 0.3. A force of $P\ \text{N}$ acts on the particle up the line of greatest slope, and the particle accelerates down the plane at $0.5\ \text{m s}^{-2}$. Mia writes "$P + 2g\sin 30° - F = 2(0.5)$, with friction acting down the slope". Explain Mia's mistake and find P. [5 marks]



Answer .....

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C3 A crate of weight W N is pushed across a rough horizontal floor at constant speed by a force of P N acting at 30° below the horizontal. The coefficient of friction is $\frac{1}{4}$. Jo writes "$R = Wg - P\sin 30^\circ$". Explain both of Jo's mistakes, and find P in terms of W. [5 marks]

Answer .....

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C4 A particle of mass $3\ \text{kg}$ rests on a rough plane inclined at 25° to the horizontal. The coefficient of friction is 0.6. Ella writes "the friction force is $\mu R = 0.6 \times 3g\cos 25^\circ = 16.0\ \text{N}$". Explain why Ella is wrong and find the friction force. [4 marks]

Answer .....

C5 A particle of mass $2\ \text{kg}$ is placed on a rough plane inclined at 40° to the horizontal and released. The coefficient of friction is 0.5. Lee writes "the particle has zero acceleration, so it stays at rest". Decide whether the particle moves, and find its acceleration. [4 marks]

Answer .....

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D1

A lorry travelling at $18\ \text{m s}^{-1}$ along a straight horizontal road brakes so that its wheels lock. It skids and comes to rest in $30\ \text{m}$. The lorry is modelled as a particle and friction is the only resistance. Nia writes: "A heavier lorry, with the same tyres on the same road, would need a longer distance to stop from $18\ \text{m s}^{-1}$."

Nia is wrong.

(a) Find the deceleration of the lorry. [2 marks]

Answer .....

(b) Find the coefficient of friction between the tyres and the road. [3 marks]

Answer .....

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(c) Show that Nia is wrong, and find the stopping distance of a car with the same μ braking in the same way from $25\ \mathrm{m\ s^{-1}}$. [3 marks]

Answer .....

(d) State one way in which the model of friction as the only resistance could be refined, and say how it would change your answer to part (b). [2 marks]

Total for D1: 10 marks

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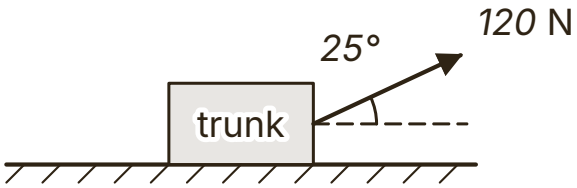
D2 A trunk of mass $30\ \text{kg}$ rests on a rough horizontal floor. A rope attached to the trunk is pulled with a force of $120\ \text{N}$ at $25°$ above the horizontal, and the trunk is on the point of moving. Find the coefficient of friction between the trunk and the floor. The tension in the rope is then increased to $150\ \text{N}$, with the rope still at $25°$ above the horizontal. Find the acceleration of the trunk. [9 marks]



Answer .....

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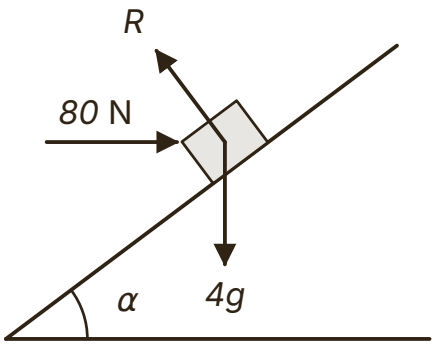
D3 A block of mass $4\ \text{kg}$ is on a rough plane inclined at an angle α to the horizontal, where $\tan\alpha = \frac{3}{4}$. The coefficient of friction between the block and the plane is 0.3.

(a) The block is released from rest with no other force acting. Show that it slides down the plane, and find its acceleration. [3 marks]



Answer .....

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(b) Instead, a horizontal force of $80\ \mathrm{N}$, in the vertical plane containing the line of greatest slope, pushes the block up the plane from rest. Find the normal reaction and the acceleration of the block. [5 marks]

Answer .....

(c) Find the speed of the block when it has moved $3\ \mathrm{m}$ up the plane. [2 marks]

Answer .....

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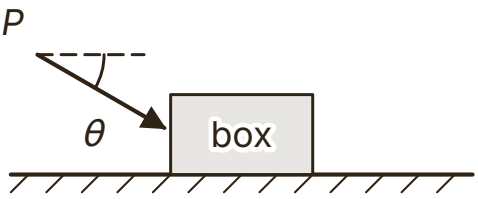
(d) The horizontal force is then changed to P N so that the block moves up the plane at constant speed. Find P. [3 marks]

Answer .....

Total for D3: 13 marks

D4 A box of mass 25 kg rests on a rough horizontal floor. The coefficient of friction between the box and the floor is 0.4. A person pushes the box with a force of P N acting at an angle θ below the horizontal.

(a) Given that $\theta = 30^\circ$ and $P = 200$, show that the box moves and find its acceleration. [4 marks]



Answer .....

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(b) Show that the box can be moved only if $P(\cos\theta - 0.4\sin\theta) > 98$. Hence explain why, if $\tan\theta \geq 2.5$, the box cannot be moved however large P is. [4 marks]

Answer .....

(c) Given that $\theta = 70^\circ$ and $P = 500$, find the friction force on the box. [2 marks]

Answer .....

Total for D4: 10 marks

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D5 A child on a sledge, of total mass $35\ \text{kg}$, slides from rest down a straight snow slope inclined at 15° to the horizontal. The sledge travels $40\ \text{m}$ down the slope in $8\ \text{s}$. The child and sledge are modelled as a particle and the coefficient of friction between the sledge and the snow is μ.

(a) Find the acceleration of the sledge down the slope. [2 marks]

Answer .....

(b) Find μ. [4 marks]

Answer .....

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(c) At the bottom of the slope the snow becomes horizontal. The sledge moves on in a straight line with the same coefficient of friction until it stops. Find the speed at the bottom of the slope and the distance the sledge travels on the horizontal snow. [4 marks]

Answer .....

(d) Give one limitation of the model used, other than the sledge being treated as a particle. [2 marks]

Total for D5: 12 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 box of mass $40\ \text{kg}$ is on a rough horizontal floor. When it is pulled by a force of $P\ \text{N}$ acting at 30° above the horizontal, it moves at constant speed. When the same force of $P\ \text{N}$ instead pushes the box at 30° below the horizontal, the box moving forwards has a deceleration of $\frac{g}{10}\ \text{m s}^{-2}$. Find the coefficient of friction and the value of P. [9 marks]

Answer .....

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Extension hints

Cover these with paper. Uncover one at a time.

E1

Hint 1 Write R for each case. Pulling upwards gives $R = 40g - P\sin 30°$; pushing downwards gives $R = 40g + P\sin 30°$. In both cases the box moves, so $F = \mu R$.

Hint 2 Write the horizontal equation for each case: zero resultant for the pull, and a resultant of $40 \times \frac{g}{10}$ backwards for the push.

Hint 3 Add the two equations: the $P\cos 30°$ terms cancel and you get $\mu P = 39.2$. Substitute $P = \dfrac{39.2}{\mu}$ into the first equation to get a quadratic in μ.

How did it go?

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

I can decide whether friction is limiting and use F ≤ μR, or F = μR when a body moves or is on the point of moving.	○ ○ ○
I can find the normal reaction and the friction when a force acts at an angle to a rough surface.	○ ○ ○
I can solve problems on rough slopes, including finding μ from information about the motion.	○ ○ ○
I can explain the assumptions in a friction model and how a refinement changes an answer.	○ ○ ○

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