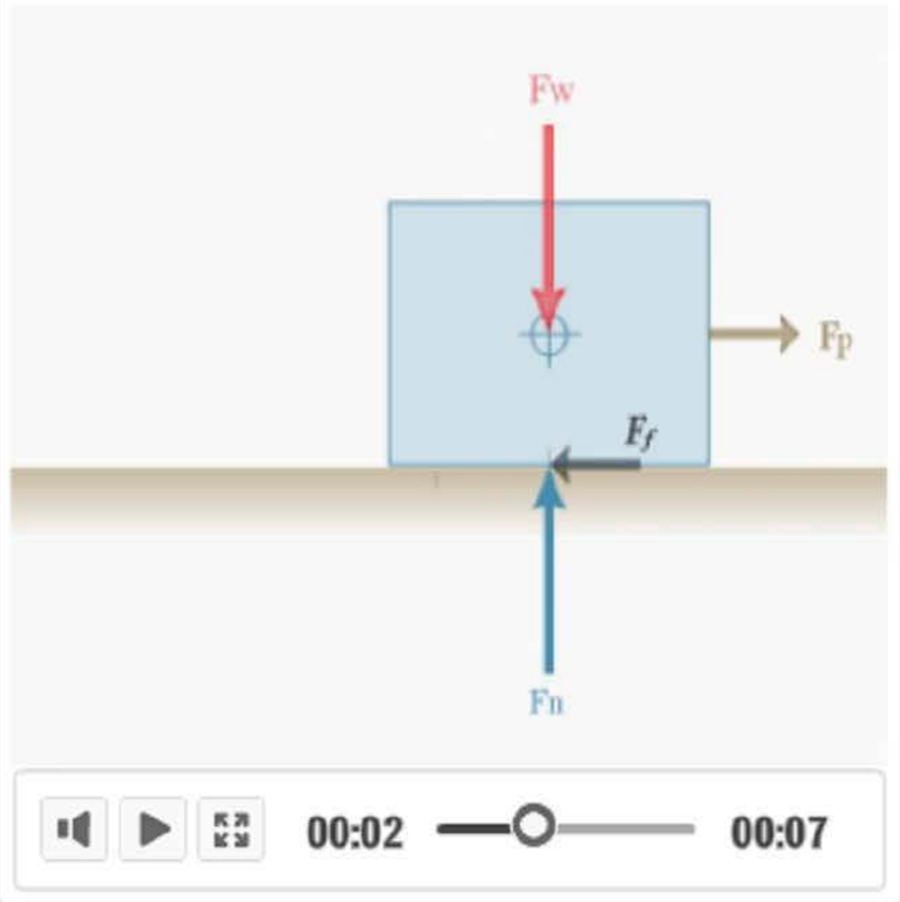
GIVE FEEDBACK

CONTINUE >

Dry sliding friction is the resistance between two surfaces in contact. This type of friction is everywhere, so much so that we tend to take it for granted.

Friction makes brakes work, it makes a bolt stay tight and it even allows a car to drive on the road. On the down side, friction causes heat and damage, as well as wasting energy.

Friction often needs to be taken into account in engineering. To make calculations possible, we need some simplifications. These turn out to be very simple when the bodies are rigid and dry (unlubricated).



The friction force F_f resists motion.

< BACK GIVE FEEDBACK OK

Most of us have a pretty good idea of what friction is. It is the grip between two surfaces rubbing on each other, like brakes for instance. It is also the grip that prevents sliding, like running shoes.

What is friction?

Friction is a force that resists the sliding of one solid object over another.

It is common experience that when one object is pushed or pulled along the surface of another object, there is resistance to such motion which must be overcome by applying an external force. The property of the two surfaces that causes this resistance is called **friction**.

To maximise traction is to maximise friction

GIVE FEEDBACK

OK

Select all statements that correctly describe friction.

Check all that apply.

- [ ] The force that opposes motion at the interface of one object sliding against another
- [ ] The force that prevents motion at the interface of one object trying to slide against another
- [ ] The force in the direction of motion as one object slides against another
- [ ] A property of the two surfaces in contact

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The fancy word for the study of friction is tribology, which also includes lubrication.

Tribology

Friction occurs in almost every engineering application. The magnitude and effects of friction are studied in mechanics, using the methods of statics.

The study of friction and its related subjects of wear and lubrication is called **tribology**.

GIVE FEEDBACK

OK

The study of friction and its related subjects of wear and lubrication is called ____.

Click the correct answer.

- tribology
- frictionology
- teleology
- rheology

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

It might look simple, one thing sliding on another, but it is actually very complicated. So we can't actually calculate friction, we can only measure it by experiment.

Dry sliding friction between solid objects can be approximated with relatively simple laws, but how it actually works is complicated.

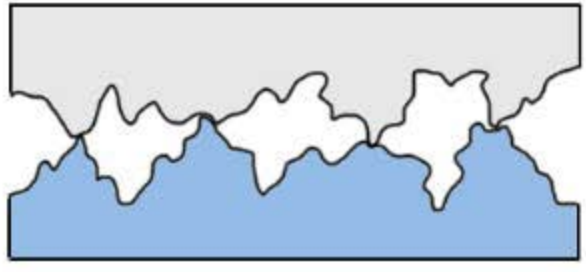
The exact mechanism behind friction arises from a combination of:

- microscopic adhesion (weak atomic bonding)
- interference due to surface roughness (interlocking)
- microscopic surface deformation (ploughing, which causes wear)
- surface contamination (foreign particles).

GIVE FEEDBACK

CONTINUE >

Development of the theory is ongoing. In 1950 Bowden and Tabor showed that at a microscopic level, the actual area of contact between surfaces is a very small fraction of the apparent area. This actual area of contact, caused by 'asperities' (roughness), increases with pressure, so is proportional to the normal force, i.e. $F_f = \mu F_n$. This also expains why Admonton's 2nd law (Friction independent of area) is less accurate for deformable materials, like rubber tyres.



Asperities: The irregularities in the surface of the object. Even a smooth surface looks like this under high magnification.

Which of the following are examples of dry sliding friction between solid objects?

Check all that apply.

- [ ] A train wheel on a rail
- [ ] Rubber tyre on a road
- [ ] A plain (non-roller) bearing surface on a crankshaft
- [ ] A fridge magnet
- [ ] An automotive disc brake

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Match the following:
The exact mechanism behind friction arises from a combination of:

Drag statements on the right to match the left.

microscopic adhesion	⇔	weak atomic bonding
interference due to surface roughness	⇔	interlocking
microscopic surface deformation	⇔	ploughing, which causes wear
surface contamination	⇔	foreign particles

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Friction is both good and bad. The good side is that it gives grip and holds things together.

The useful effects of friction

Some frictional effects are beneficial, such as the traction needed to walk without slipping.

The operation of brakes, clutches and power transmission belts depends on the presence of friction. Friction also makes the wheels of a locomotive grip the rails.

Many fasteners rely on friction, otherwise they would come undone. The thread of a bolt and the friction under the bolt head (or nut) must have enough friction to prevent loosening. Friction also holds spring pins, taper pins, wedges and nails in place. Even the knot in a rope is held together by friction.

GIVE FEEDBACK

CONTINUE >

Without friction we might save some energy, but tyres and brakes would not work, and houses and cars would fall apart.

Friction is critical for wheelnuts, tyres and brakes... (and gloves)

Select all of the following joining methods that rely on surface friction.

Check all that apply.

- [ ] bolts
- [ ] screws
- [ ] nails
- [ ] welds

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Identify whether friction would be **helpful** or **harmful** in each of the following examples.

Drag statements on the right to match the left.

helpful	bolts
helpful	nails
helpful	brakes
harmful	bearings
harmful	gears
harmful	efficiency of motion

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The bad side of friction is mostly about energy being wasted, as well as wear and tear on parts.

The detrimental effects of friction

Some of the power used to drive machinary is wasted in overcoming friction between moving parts. Friction tends to produce heat and wear, necessitating costly repairs and replacements. Lubrication helps to reduce frictional resistance and wear between moving machinery parts and is therefore widely used.

It is almost impossible to get rid of friction completely. The closest we can get is to use non-contact magnetic bearings running in a vacuum. This is employed by high speed flywheels for energy storage.

GIVE FEEDBACK

CONTINUE >

Motors can get hot due to electrical resistance or fuel combustion, but when a gearbox or drive system gets hot, this indicates power wasted solely by friction.

Friction can also cause vibration, such as squealing brakes or squeaky hinges.

Heat in a gearbox is due to friction

Which of the following statements about the symptoms of friction are true?

Check all that apply.

- [ ] Friction is the main cause of heat in a gear box
- [ ] Friction is the main cause of heat in a petrol engine
- [ ] Less friction means less heat is generated
- [ ] The whining sound of a car's reverse gear (spur gears) shows it has more friction than the quiet forward gears (helical gears)

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Match the following statements about friction in machinery.

Drag statements on the right to match the left.

Friction tends to produce	heat and wear
Lubrication helps to	reduce friction and wear between moving parts
The closest we can get to zero friction is to use	non-contact magnetic bearings running in a vacuum
When a gearbox or drive system gets hot, this indicates	power wasted by friction

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Although this chapter is about sliding friction, rolling friction works with similar laws–excpet the friction is much lower of course.

Rolling Resistance

Another form of resistance similar to friction, known as **rolling resistance**, is produced when a deformable tyre rolls over a surface. The main reason for rolling friction is deformation, which occurs when the tyre is slightly flattened and the road surface is somewhat indented at the point of contact.

Rolling friction is generally much lower than sliding friction, which is why ball or roller bearings are used to reduce frictional resistance to rotational motion of shafts and wheels.

Linear bearings also exist to provide low friction motion in a straight line.

Since rolling friction is related to deformation, it can be reduced by using stiffer and more elastic materials—such as hardened steel rollers or higher air pressure in tyres.

Rolling element bearings

GIVE FEEDBACK

OK

Match the following statements about friction of a rolling contact.

Drag statements on the right to match the left.

When a deformable object rolls over a surface, the friction is called	rolling resistance
The main reason for rolling friction is	deformation of the roller and surface
Rolling friction is generally much lower than	sliding friction
Rolling friction is lowest when using materials that are	stiff and elastic

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Compared to sliding friction, rolling friction is _____.

Click the correct answer.

- lower
- higher
- negative
- the same

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Unlike dry sliding friction between solid objects, fluid friction (or drag) increases dramatically with increasing speed.

Air resistance in terms of friction

When a vehicle or projectile is travelling through the air, there is a friction-like force that works to slow it down. This can occur in all fluids (gases and liquids).

Mathematical treatment of fluid resistance is too complex to analyse here, but it could be summarised as a combination of:

- form drag: shape related pressures that work against the motion. This is where the drag coefficient C_D is used. A more aerodynamic shape has a lower C_D.
- skin friction: the grip of the air on the surface of the body. This is effected by the surface but cannot be reduced to zero. It is usually much smaller than form drag.

GIVE FEEDBACK

CONTINUE >

The drag force is very sensitive to speed, which is completely opposite to Coulomb's law of dry sliding friction which states velocity has no effect.

Remember: all forms of friction generate forces that resist motion (trying to slow it down).

Aircraft are designed to minimise drag.

Match terms used in fluid resistance to their description.

Drag statements on the right to match the left.

Form drag	⇔	Shape-related pressures that works against the motion
Skin friction	⇔	The grip of the fluid on the surface of the body
C_D	⇔	Drag coefficient

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Which of the following statements about fluid friction are correct?

Check all that apply.

- [ ] A friction-like force occurs for any moving body in either gases or liquids
- [ ] A more aerodynamic shape has a higher drag coefficient
- [ ] Drag force increases with speed
- [ ] In air, skin friction is usually lower than form drag

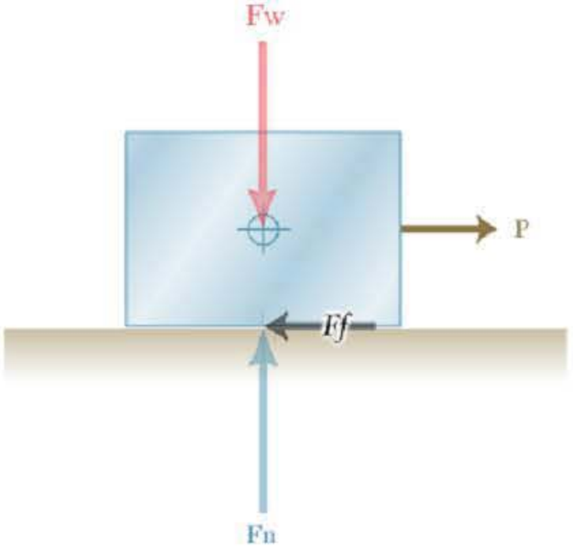
Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The laws of friction have been studied since Leonardo Da Vinci in the 1400s. There are three laws of dry sliding friction. The most surprising is the second one–friction does not depend on area of contact.

The classic laws of dry sliding friction

Although Leonardo Da Vinci wrote these rules more than a century earlier, credit goes to Guillaume Amonton who published them in 1699. Later, Charles Coulomb (also a French scientist) added his investigation of dry friction in 1781. The theory of dry friction often bears the name of Coulomb friction.



Friction force is shown as Ff

The laws of dry sliding friction between rigid objects:

1. The force of friction is directly proportional to the applied load. (Amontons' 1st Law)
2. The force of friction is independent of the apparent area of contact. (Amontons' 2nd Law)
3. Kinetic friction is independent of the sliding velocity. (Coulomb's Law)

GIVE FEEDBACK

OK

Match the three laws of dry sliding friction between rigid objects.

Drag statements on the right to match the left.

The force of friction is directly proportional to the applied load	Amontons' 1st Law
The force of friction is independent of the apparent area of contact	Amontons' 2nd Law
Kinetic friction is independent of the sliding velocity	Coulomb's Law

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

According to Amontons' 2nd Law:

The force of friction is independent of the area of contact.

But wider car tyres give better grip on a dry road. Why do tyres seem to disobey this law?

Click the correct answer.

- They are soft and these laws apply best to rigid bodies
- The car tyre is rolling, not sliding
- The tyre has a tread pattern
- Heating of the rubber changes the coefficient of friction

Do you know the answer?

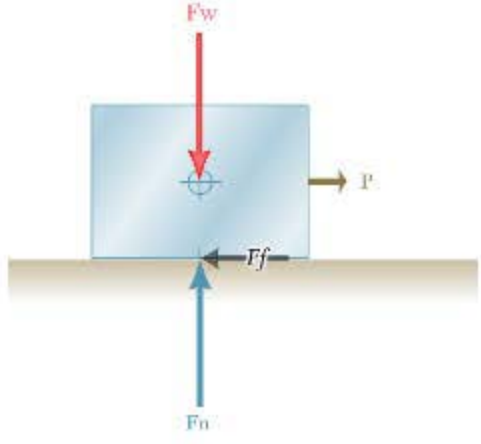
I KNOW IT | THINK SO | UNSURE | NO IDEA

As with all problems in static equilibrium, we begin with a free body diagram–often abbreviated to FBD.

The forces acting on a body in the case of static friction

Consider a solid block, such as a brick, resting on a horizontal table surface. The weight (F_w) acts downwards and an equal and opposite normal reaction (F_n) pushes up from the table.

If a small push (F_p) is applied to the block and it does not move, there must be a friction force (F_f), equal and opposite to the push, at the surface of contact between the block and the table.



GIVE FEEDBACK

CONTINUE >

When setting up a FBD for a friction problem we will use labels **n**=normal and **p**=perpendicular as local coordinates based on the planar surface.

Later on, we are planning to tilt the ground surface, so it is better not to use global coordinates like H and V (for horizontal and vertical), or X and Y.

Match the following terms used in a free body diagram (FBD) of a body with friction.

Drag statements on the right to match the left.

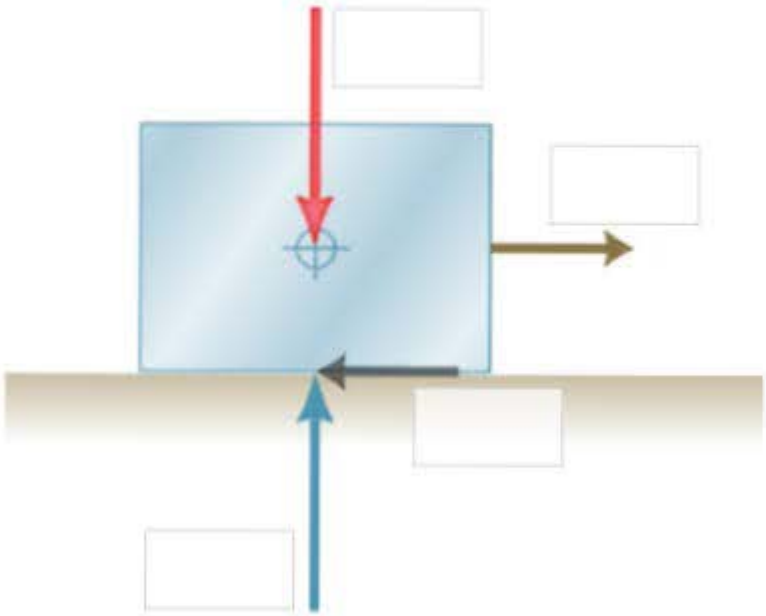
F_w	Weight force
F_p or P	Applied force
F_n	Normal force from the ground
F_f	Friction force

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Label the free body diagram.

F_w F_n F_f F_p



Submit

Match the equal and opposite forces in a free body diagram (FBD) of a body with friction.

Drag statements on the right to match the left.

F_w	⇔	F_n
F_p or P	⇔	F_f

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Friction can prevent movement up to a point. With any increase in horizontal force the block will move.

The limiting value of static friction force

If the push P is increased gradually, it will eventually cause the block to slide on the table.

Video object isn't supported in c++ version

There is a limiting value of the force of friction F_f beyond which it cannot increase.

Experiments show that:

- the limiting value of the friction force is the same whether the block is lying down or standing on its end, i.e. it is independent of the area in contact
- if a pile of three blocks is pushed along the table, the friction is three times greater than when one block is pushed, i.e. friction is proportional to the normal force F_n.

GIVE FEEDBACK

OK

The limiting value of friction force is _____.

Video object isn't supported in c++ version

Click the correct answer.

- the point at which the block cannot take any more force before it moves
- the highest value of normal force that occurs
- the friction force required to stop a moving object
- the same value whether it is one block or three blocks stacked together

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

What fraction of an object's weight does it take to pull it along? This ratio of weight to friction force is called the coefficient of friction.

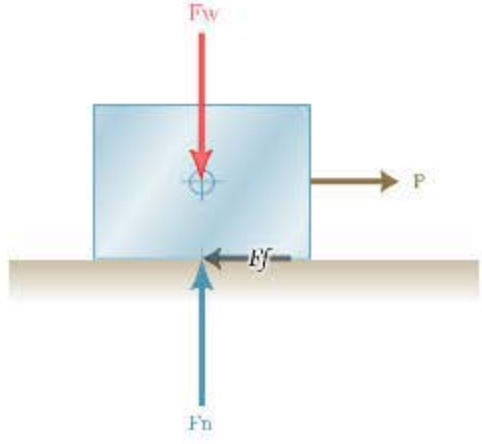
The coefficient of static friction

At the moment of impending motion, the value of F_f is always a **fixed ratio** of the normal force F_n.

That ratio depends on the materials and the roughness of the contacting surfaces. It is called the **coefficient of static friction** and is given the Greek letter μ (mu).

$$\mu = \frac{F_f}{F_n}$$

For example, the diagram on the right shows F_f about 60% of F_n, which would give a value of $\mu = 0.6$.



GIVE FEEDBACK

OK

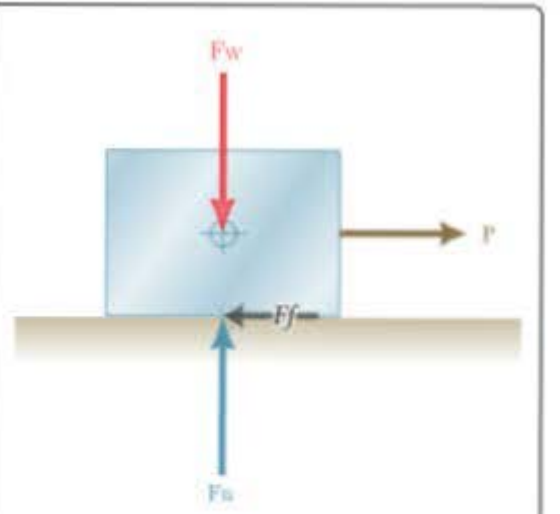
Drag the forces to the correct positions according to the equation for the coefficient of friction.

F_n F_f

$$\mu = \frac{\square}{\square}$$

Submit

The diagram on the right shows F_f about 60% of F_n, which would give a value of _____.



Click the correct answer.

- 0.6
- 60
- 1.667
- 166.7

Owing to the variation in friction with the condition of the rubbing surfaces, it is impossible to specify exact values for each pair of materials in contact. Typical engineering materials with clean, unlubricated surfaces have friction coefficients in the range 0.2 to 0.4. Below are some generally accepted approximate values. These coefficients are measured by experiment because the surface interactions are too complex for a simple and reliable formula.

Surface pair	*Typical value*	*Usual range*
metal on metal (greasy)	0.1	0.08-0.2
hardwood on metal (greasy)	0.2	0.15-0.3
metal on metal (dry)	0.2	0.15-0.35
wire rope on metal pulley	0.2	0.15-0.4
hemp rope on metal pulley	0.3	0.2-0.5

Surface pair	*Typical value*	*Usual range*
wood on wood	0.35	0.25-0.5
hardwood on metal (dry)	0.35	0.2-0.6
rubber or leather on metal	0.4	0.3-0.6
brake lining on metal	0.4	0.3-0.7
metal on stone	0.4	0.3-0.7
wood on stone	0.4	0.3-0.7
masonry on brickwork	0.6	0.55-0.7
rubber tyre on concrete	0.8	0.6-1.0

How is the coefficient of friction determined for dry sliding friction?

Click the correct answer.

- By experiment
- By the ratio of atomic masses
- By calculating molecular attractive forces
- By measuring surface roughness

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The ***coefficient of static friction*** μ _____.

Check all that apply.

- [ ] is an approximate value for a particular pair of surfaces
- [ ] is lower when the surfaces are lubricated
- [ ] is usually in the range 0.2 to 0.4 for typical engineering materials
- [ ] is always less than 1

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The coefficient of friction has no units. It just has a ratio, a number.

The SI unit of coefficient of static friction

Because both friction and normal forces are measured in units of force (i.e. Newtons), the coefficient of static friction is dimensionless.

From the equation: $\mu = \frac{F_f}{F_n}$, the units for $\mu = \frac{(N)}{(N)} = 1$, which is dimensionless.

A dimensionless value is simply a number (e.g. The dimensionless number π is also a ratio of two units that cancel out, because π = circumference/diameter, which is always 3.14159265359...).

GIVE FEEDBACK

OK

The standard units for coefficient of friction are _____.

Click the correct answer.

- none
- N
- N/mm
- N/N

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Lubrication dramatically reduces friction. It changes some of those friction laws a bit too. We will not be looking at lubrication in any detail.

The effect of liquid lubricants on the friction coefficient

The presence of a liquid lubricant completely changes the character of friction and often has a profound effect on the friction coefficient.

Good lubricants are able to reduce the coefficient of friction to as low as 0.05. A typical range for μ of lubricated polished surfaces is 0.08 to 0.15.

GIVE FEEDBACK

OK

A typical range for μ can be from 0.08 to 0.15
for surfaces that are polished and Select...

Submit

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The moment of impending motion is the last moment before the block moves. Friction cannot sustain any more force than this.

The force required to overcome friction

Video object isn't supported in c++ version

The friction described up until now is that which arises between surfaces at rest with respect to each other (static).

The moment of **impending motion** is the last moment before the block moves.

The force (F_p) required to overcome static friction and to start motion is:

$$F_p = F_f = \mu F_n$$

GIVE FEEDBACK

OK

The force (F_p) required to overcome static friction and to start motion is _____.

Click the correct answer.

$F_p = F_f = \mu F_n$

$F_p = \frac{F_n}{\mu}$

$F_p = F_w \cdot \mu$

$F_p = \frac{\mu}{F_f}$

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

This graph shows that friction will increase to a maximum called the static friction. After it breaks traction and starts moving, friction is lower. This is called kinetic friction.

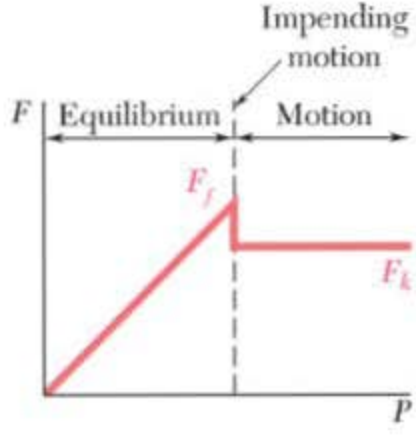
Typical values of static and kinetic friction compared

The limiting force to overcome **static friction** was found by:

$F_p = F_f = \mu F_n$

Once the motion begins, the force required to continue the motion is called **kinetic friction force**. This is the force required to maintain motion against continuous frictional resistance.

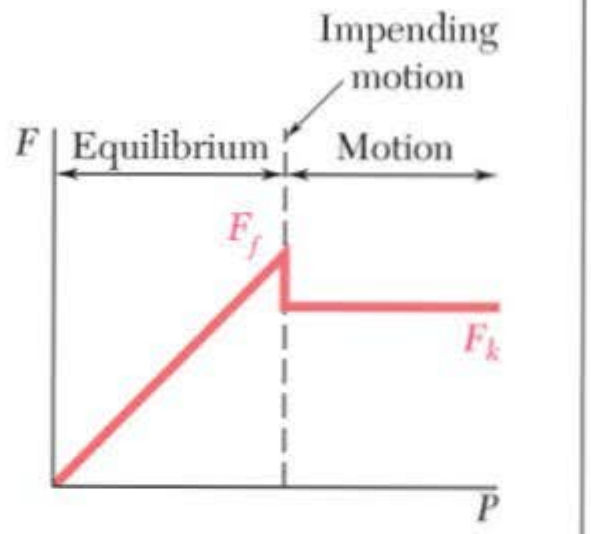
This is shown in the diagram at right. Kinetic friction force F_k is typically about 25% less than the limiting static friction F_f .



GIVE FEEDBACK

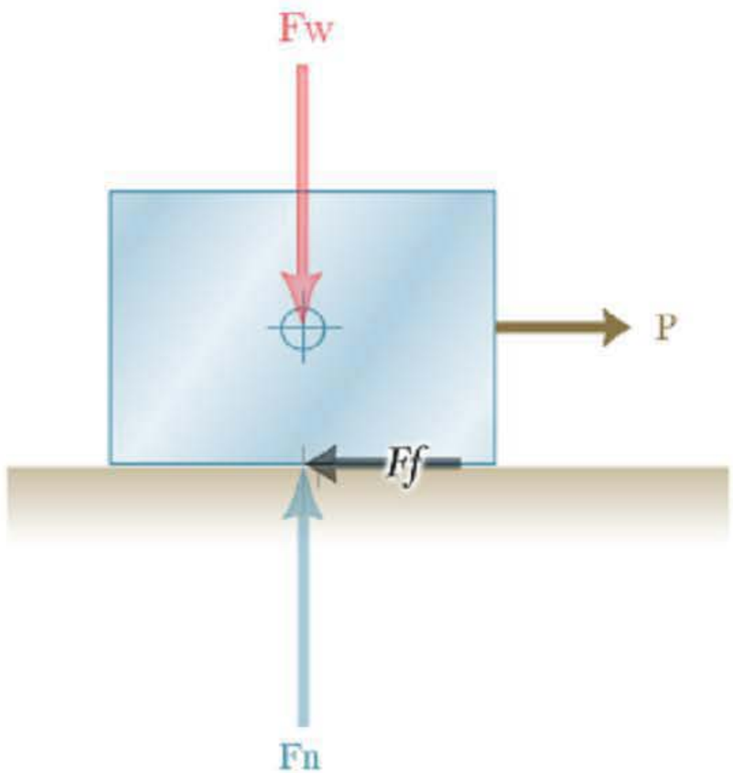
OK

What does this diagram tell us about friction?



Check all that apply.

- [ ] Kinetic friction is less than static friction
- [ ] Static friction is less than kinetic friction
- [ ] Once motion occurs friction goes down
- [ ] Once motion occurs friction goes up



Match what happens to the friction force F_f for each modification made below.

Assume the kinetic friction is lower than the static friction, and the laws of dry sliding friction apply.

Drag each item into appropriate category.
Click on an item to send it to the back of the stack.

Extra weight is added to the block

F_f will increase	F_f will not change	F_f will decrease

These are the rules and assumptions we will make when analysing friction problems.

Rules for calculating dry sliding friction

The **rules for calculating friction** can be summarised as follows:

2. Friction always acts in a direction opposite to impending or actual motion.
3. Static friction has a limiting value beyond which it cannot increase.
4. The limiting value of static friction is given by $F_f = \mu F_n$.
5. The value of the coefficient of static friction (μ) depends on the nature and condition of the surfaces in contact, but is independent of the areas in contact.
6. In general, kinetic friction is less than the limiting static friction.

GIVE FEEDBACK

OK

According to the rules for calculating dry sliding friction for rigid bodies, the value of the coefficient of static friction (μ) will vary depending on _____.

Click the correct answer.

- the area of contact
- the normal force pressing the two surfaces together
- the nature and condition of the surfaces in contact
- the speed of the motion

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

In what direction does friction always act?

Click the correct answer.

- Against motion
- Against impending motion
- Against gravity
- Against the normal force

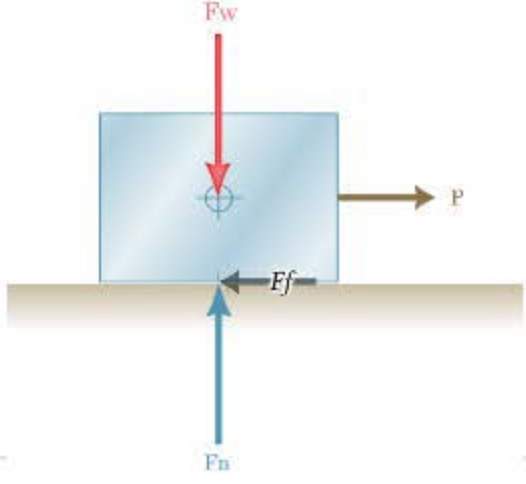
Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Calculate the force required to start a body moving

EXAMPLE

A 5 kg block rests on a horizontal surface. Coefficient of friction is 0.33. What horizontal force will start the body moving?



SOLUTION

Weight of body: $F_w = m\,g$

$= 5\ \text{kg} \times 9.81\ \text{N/kg}$

$= 49.05\ \text{N}$

Normal force: $F_n = F_w = 49.05\ \text{N}$

So the force F_P required to just start the body moving is equal to the friction force F_f, where limiting friction force $F_f = \mu F_n$;

$F_p = F_f$

$= 0.33 \times 49.05\ \text{N}$

$= 16.2\ \text{N}$

GIVE FEEDBACK

OK

A body of mass 155 kg rests on a horizontal surface and the coefficient of friction between the two surfaces is 0.33. What horizontal force will be required to start the body moving? (Round off to nearest integer. Include units).

Clear

Clear line

Undo

Click and type your answer here

CHALLENGE

SUBMIT

SHOW ANSWER

INSTRUCTIONS

- No intermediate steps are required
- If you choose to show steps, write one on each line.
- Write your final answer on the last line.
- The computer will check all your work in detail when you click "Submit".

Hint

Each hint will reduce the credit received for this question

A 800 kg machine is mounted on Teflon pads which slide on horizontal Teflon guide rails. The coefficient of friction is 0.04. What horizontal force will be required to start the body moving? (Round off to nearest integer. Include units)

+ − · ÷ □/□ □² ▼ √□ (□) ▼ ≤ ▼ π N f (x) ▼

Clear

?

Undo

Click and type your answer here

CHALLENGE

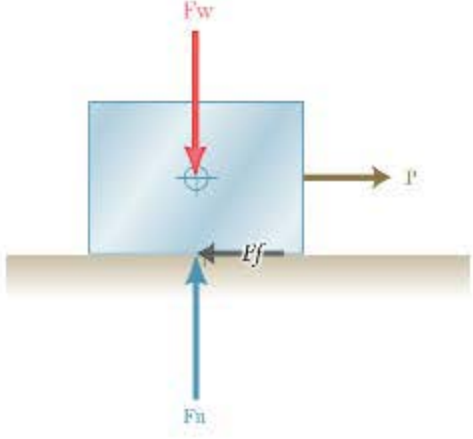
SUBMIT

SHOW ANSWER

Calculate the coefficient of static friction--Example

Example

In an experiment to measure the coefficient of friction, a horizontal force of 50 N was required to start a 10 kg block moving on a horizontal surface. What was the value of the coefficient?



Solution

$F_n = F_w = m\,g$

$\therefore F_n = 10\ \text{kg} \times 9.81\ \text{N/kg}$

$= 98.1\ \text{N}$

By horizontal equilibrium;

$F_f = F_p$

$\therefore F_p = 50\ \text{N}$

From friction definition;

$$\mu = \frac{F_f}{F_n} = \frac{50\ \text{N}}{98.1\ \text{N}} = 0.51$$

GIVE FEEDBACK

OK

A body of mass 60 kg rests on a horizontal surface and a horizontal force of 250 N was required to start the body moving. Determine the coefficient of friction between the two surfaces. (Use at least 3 decimal places.)

Click and type your answer here

CHALLENGE SUBMIT SHOW ANSWER

INSTRUCTIONS

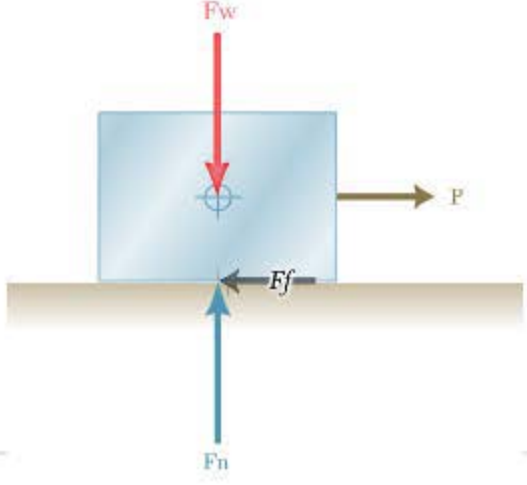
- No intermediate steps are required
- If you choose to show steps, write one on each line.
- Write your final answer on the last line.
- The computer will check all your work in detail when you click "Submit".

Hint Each hint will reduce the credit received for this question

Calculate the mass for a given force and friction coefficient--Example

Example

Find the highest mass that can be dragged along a horizontal surface if the coefficient of friction is 0.44 and the applied horizontal force is 648 N.



Solution

From $F_f = \mu \cdot F_n$

$$F_n = \frac{F_f}{\mu} = \frac{648\ \text{N}}{0.44} = 1{,}472.7\ \text{N}$$

Since $F_n = F_w$ then mass is:

$$m = \frac{F_w}{g} = \frac{1{,}472.7}{9.81} = 150.1\ \text{kg}$$

So mass = 150.1 kg

GIVE FEEDBACK

OK

Calculate the highest mass that can be pulled along on a horizontal Teflon rail if the coefficient of friction is 0.04 and the applied horizontal force is 2000 N.

(Round off answer to nearest integer. Include units)

+ − · ÷ □/□ □² √□ (□) ≤ π kg f(x) ↵

Clear

Clear line

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Click and type your answer here

CHALLENGE

SUBMIT

SHOW ANSWER

INSTRUCTIONS

- No intermediate steps are required
- If you choose to show steps, write one on each line.
- Write your final answer on the last line.
- The computer will check all your work in detail when you click "Submit".

Hint

Each hint will reduce the credit received for this question

Calculate the highest mass that can be dragged along a horizontal surface if the coefficient of friction is 0.43 and the applied horizontal force is 2000 N.

(Round off answer to nearest integer. Include units)

Click and type your answer here

CHALLENGE SUBMIT SHOW ANSWER

INSTRUCTIONS

- No intermediate steps are required
- If you choose to show steps, write one on each line.
- Write your final answer on the last line.
- The computer will check all your work in detail when you click "Submit".

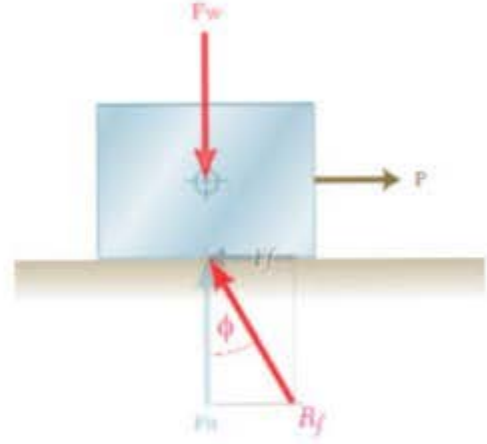
Hint Each hint will reduce the credit received for this question

Another way to analyse friction is to set up the problem using a single reaction force that combines the friction force and normal force.

Define resultant of frictional support reaction

Another approach to the analysis of friction on a horizontal plane is to combine the force of friction (F_f) and the normal reaction (F_n) into a single resultant force (R_f).

This represents the total reaction at the surface of contact to the action of weight (F_w) and applied force (F_p).



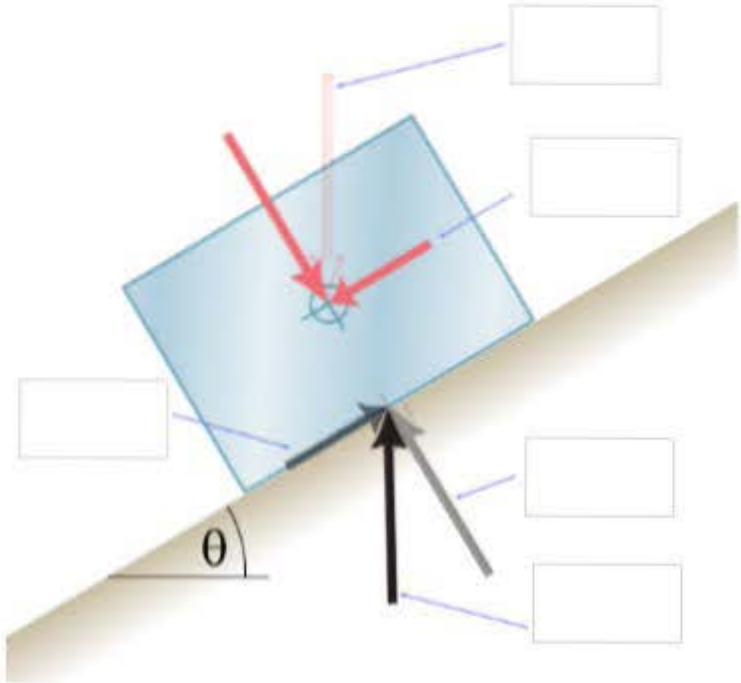
The friction force and the normal reaction combined into a single resultant force

GIVE FEEDBACK

OK

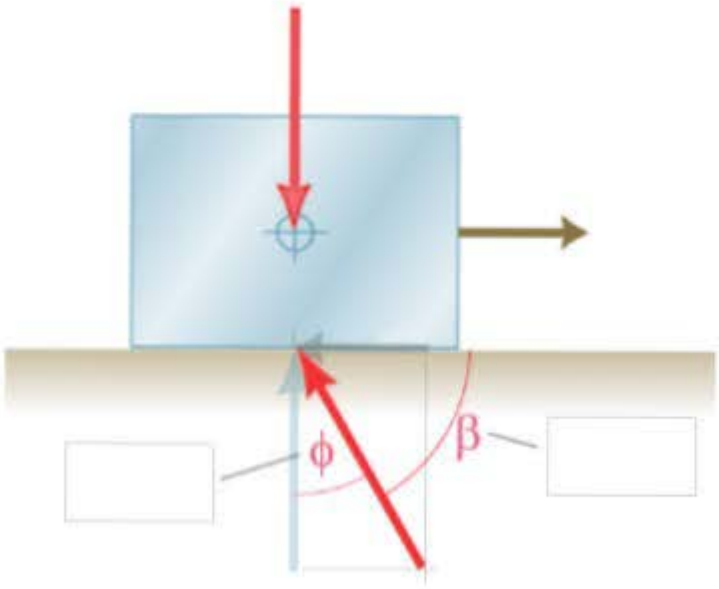
Label the free body diagram for the resultant friction reaction, where:
Fw = weight, Fn = normal component of reaction force, Ff = friction force, Fp = parallel component of reaction force, Fr = reaction force.

F_w F_n F_f F_r F_p



Label the angle of friction.

Angle



Submit

Formulas required to calculate the resultant force and angle of friction

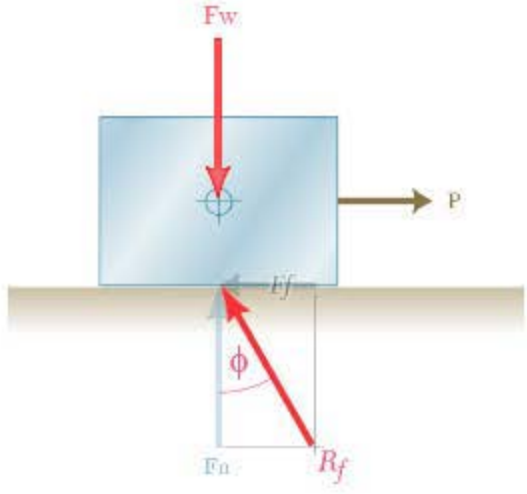
This represents the total reaction at the surface of contact to the action of weight (F_w) and applied force (F_p).

The resultant force (F_r) will be inclined at an angle to the normal direction. Using the rules for finding resultants of two mutually perpendicular forces yields:

$$F_r = \sqrt{F_f^2 + F_n^2}$$

and:

$$\tan \Phi = \frac{F_f}{F_n}$$



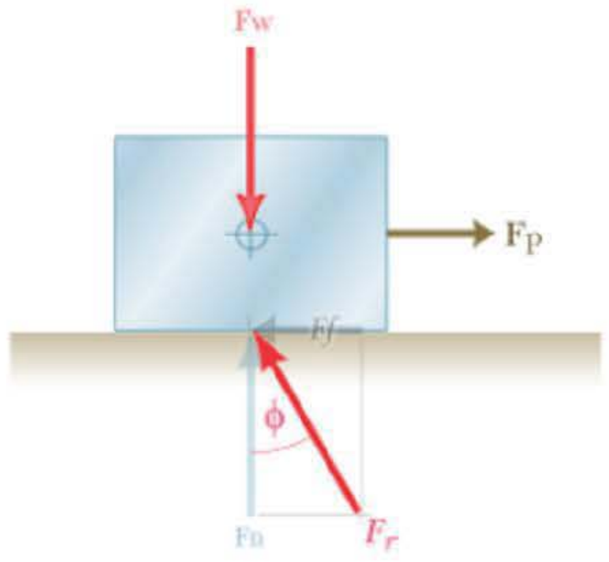
The friction force and the normal reaction combined into a single resultant force

GIVE FEEDBACK

OK

Determine the resultant friction force.

Match the symbols to their correct formula.



Drag statements on the right to match the left.

F_r	$\tan^{-1}\left(\frac{F_f}{F_n}\right)$
Φ	$\sqrt{F_f^2 + F_n^2}$
μ	$\frac{F_f}{F_n}$
F_w	$m \cdot g$

When the resultant reaction force is at the point of impending motion, the angle of this force from the normal is called the angle of friction.

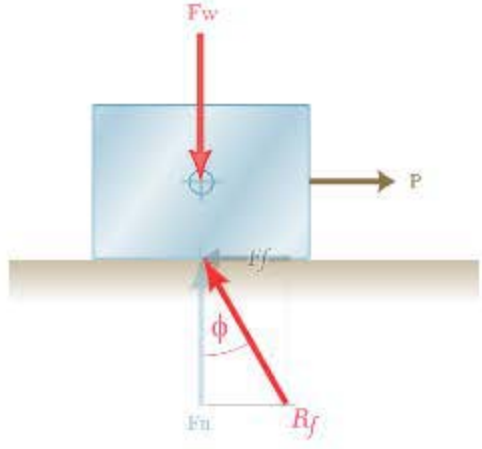
The relationship between angle of friction and coefficient of static friction

The angle if friction is $\tan \Phi = \frac{F_f}{F_n}$

But we know that at the moment when sliding motion is about to begin, the ratio of F_f to F_n is equal to the coefficient of static friction (μ). Therefore, for limiting friction:

$$\tan \Phi = \mu$$

Under these circumstances, the angle, known as the **angle of friction**, is constant and depends only on the nature and condition of the surfaces in contact.

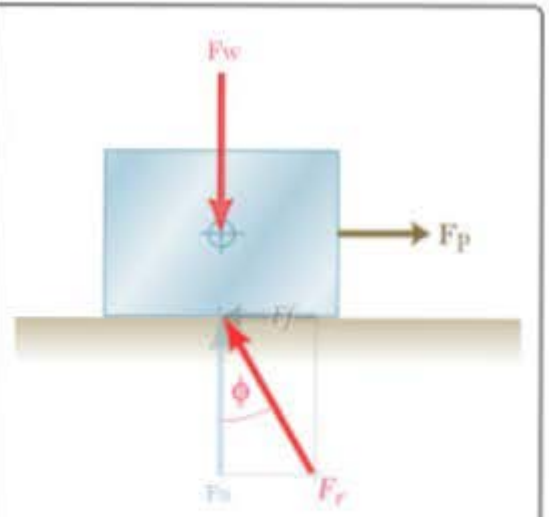


The friction force and the normal reaction combined into a single resultant force

GIVE FEEDBACK

OK

The **angle of friction** is related to the **coefficient of friction** by which equation?



Click the correct answer.

$\tan \Phi = \mu$

$\Phi = \tan \mu$

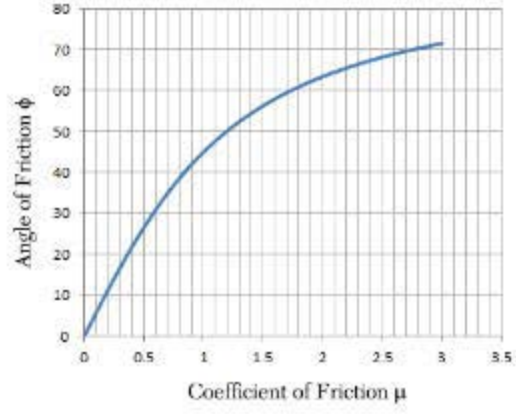
$F_r = \sqrt{F_n^2 + F_f^2}$

$\sin^2 \Phi + \cos^2 \Phi = 1$

Compare the angle of friction with the coefficient of friction

The coefficient of friction μ ranges from 0 (frictionless) through about 0.4 (typical) to more than 2 (rubber on glass). As μ increases, the angle of friction Φ approaches a maximum of 90°.

A typical coefficient of 0.4 gives an angle of friction of about
$\Phi = \tan^{-1} \mu = \tan^{-1} 0.4 = 22^{\circ}$.



GIVE FEEDBACK

OK

Select all correct statements about the angle of friction.

Check all that apply.

- [ ] The higher the angle of friction, the lower the coefficient of friction
- [ ] The angle of friction is between 0° and 90°
- [ ] Zero friction is an angle of friction of 90°
- [ ] Angle of friction is measured in degrees

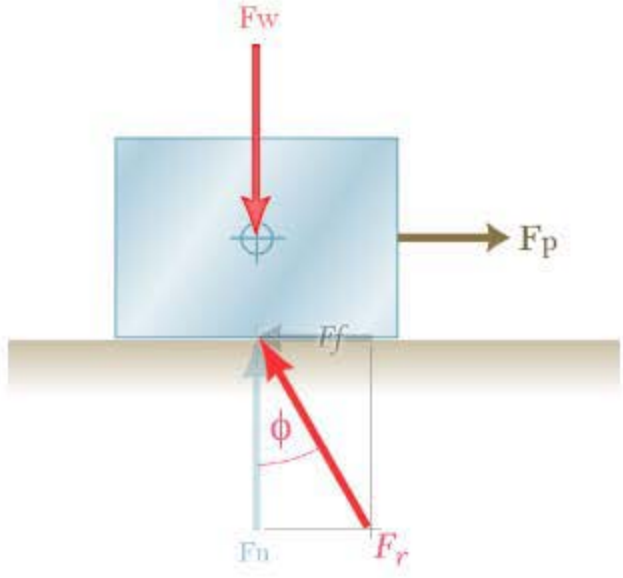
Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Calculate the angle of friction--Example

A body of mass 35 kg rests on a horizontal surface, and the coefficient of friction between the two surfaces is 0.6. A force of 52N is applied horizontally.

What is the angle of friction?



The problem	Find angle of friction	Find angle of friction

GIVE FEEDBACK

OK

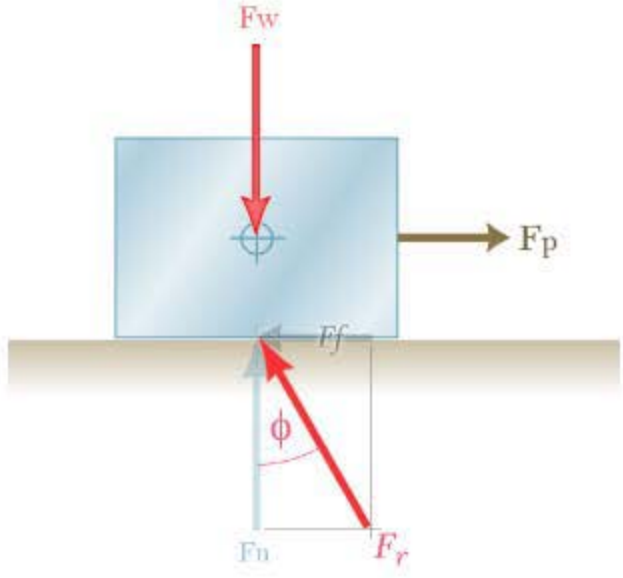
Calculate the angle of friction--Example

A body of mass 35 kg rests on a horizontal surface, and the coefficient of friction between the two surfaces is 0.6. A force of 52N is applied horizontally.

There is more information than we need here.

To get angle of friction Φ, just use μ;

$$\begin{aligned}\Phi &= \tan^{-1}\mu \\ &= \tan^{-1} 0.6 \\ &= 30.96°\end{aligned}$$



The problem	Find angle of friction	Find angle of friction

GIVE FEEDBACK

OK

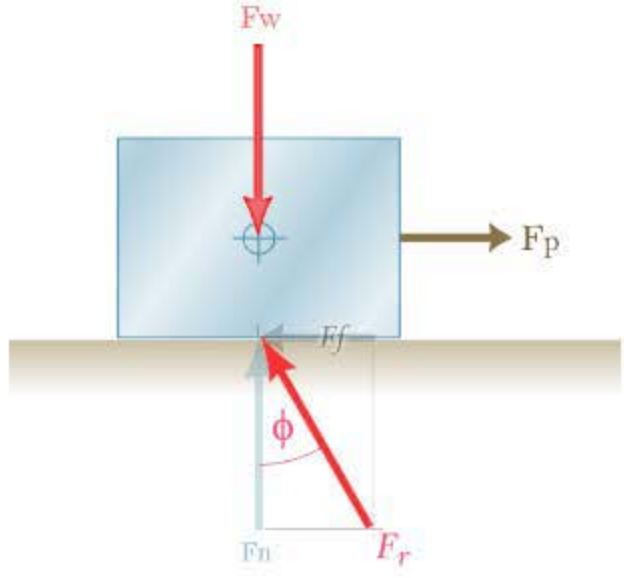
Calculate the angle of friction--Example

A body of mass 35 kg rests on a horizontal surface, and the coefficient of friction between the two surfaces is 0.6. A force of 52N is applied horizontally.

But there's more. We could also calculate the angle of the resultant friction reaction. This angle is:

$$\text{Resultant angle} = \tan^{-1}\left(\frac{F_f}{F_n}\right)$$
$$= \tan^{-1}\left(\frac{52}{343.4}\right)$$
$$= 8.61°$$

This angle is well short of the angle of friction Φ, so the block would need a lot more force to start moving.



The problem	Find angle of friction	Find angle of friction

GIVE FEEDBACK

OK

A body of mass 55 kg rests on a horizontal surface with a coefficient of friction between the two surfaces of 0. Calculate the angle of friction in degrees.

Do not include units. Use at least 1 decimal place.

+ − · ÷ □/□ □² √□ Clear

(□) ≤ π f(x) arctan □ Clear line

θ ↵ ? Undo

Click and type your answer here

CHALLENGE SUBMIT SHOW ANSWER

INSTRUCTIONS

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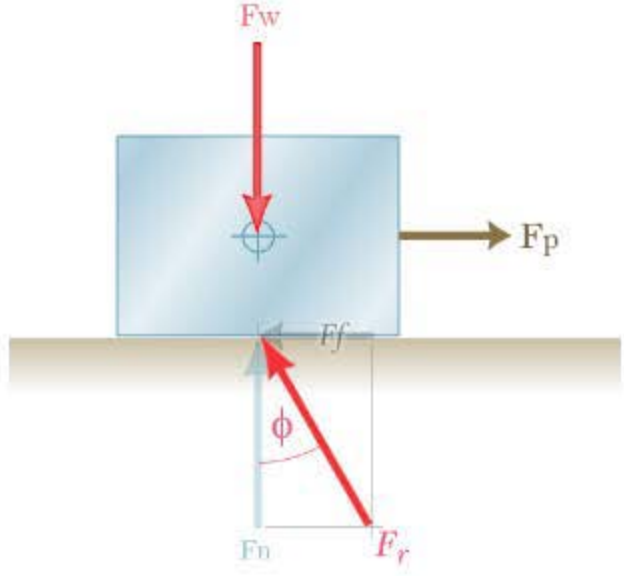
- Write your final answer on the last line.
- The computer will check all your work in detail when you click "Submit".

Hint Each hint will reduce the credit received for this question

Use the angle of friction to solve equilibrium

A body of mass 3 kg rests on a horizontal surface, and the coefficient of friction between the two surfaces is 0.3.

What horizontal force is required to start the body moving?



The problem	Weight and angle of friction	Solve for applied force

GIVE FEEDBACK

OK

Use the angle of friction to solve equilibrium

Weight of the body:

$F_w = m\,g$

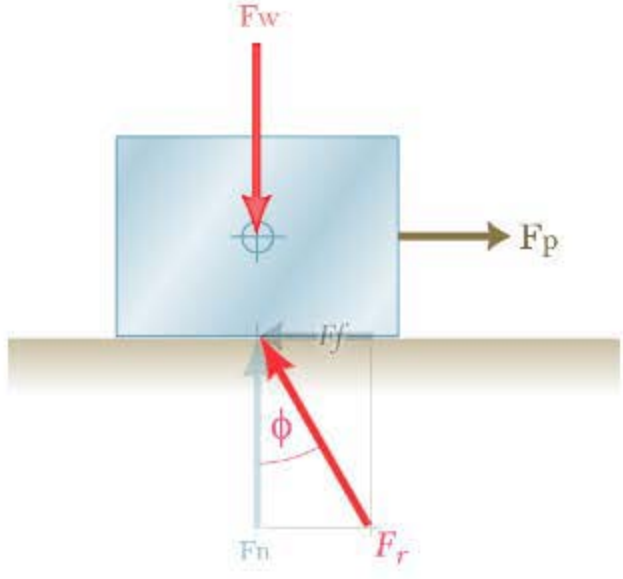
$= 3\text{ kg} \times 9.81\text{ N/kg}$

$= 29.43\text{ N}$

Angle of friction:

$\Phi = \tan^{-1} 0.3$

$= 16.7°$

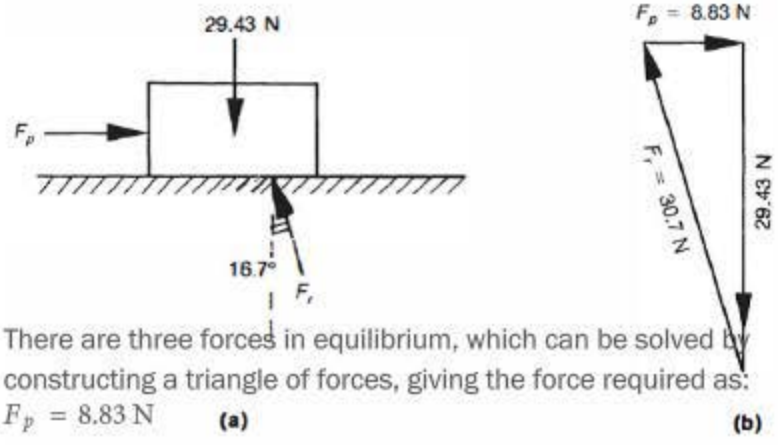


The problem	Weight and angle of friction	Solve for applied force

GIVE FEEDBACK

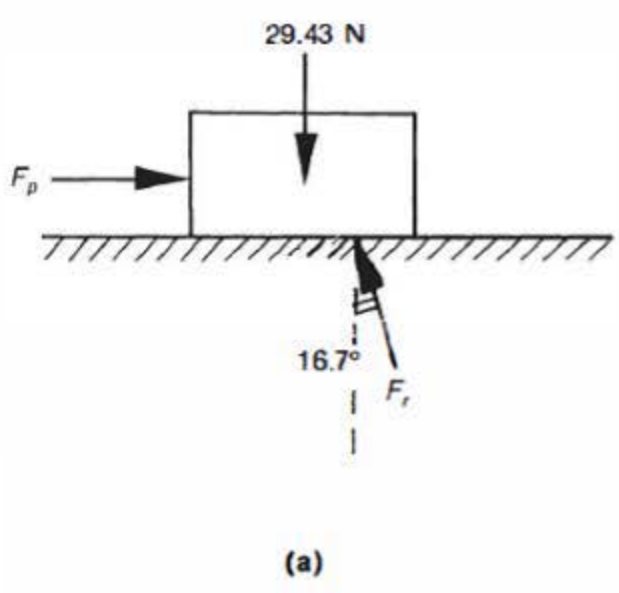
OK

Use the angle of friction to solve equilibrium



There are three forces in equilibrium, which can be solved by constructing a triangle of forces, giving the force required as:

$F_p = 8.83\,\text{N}$

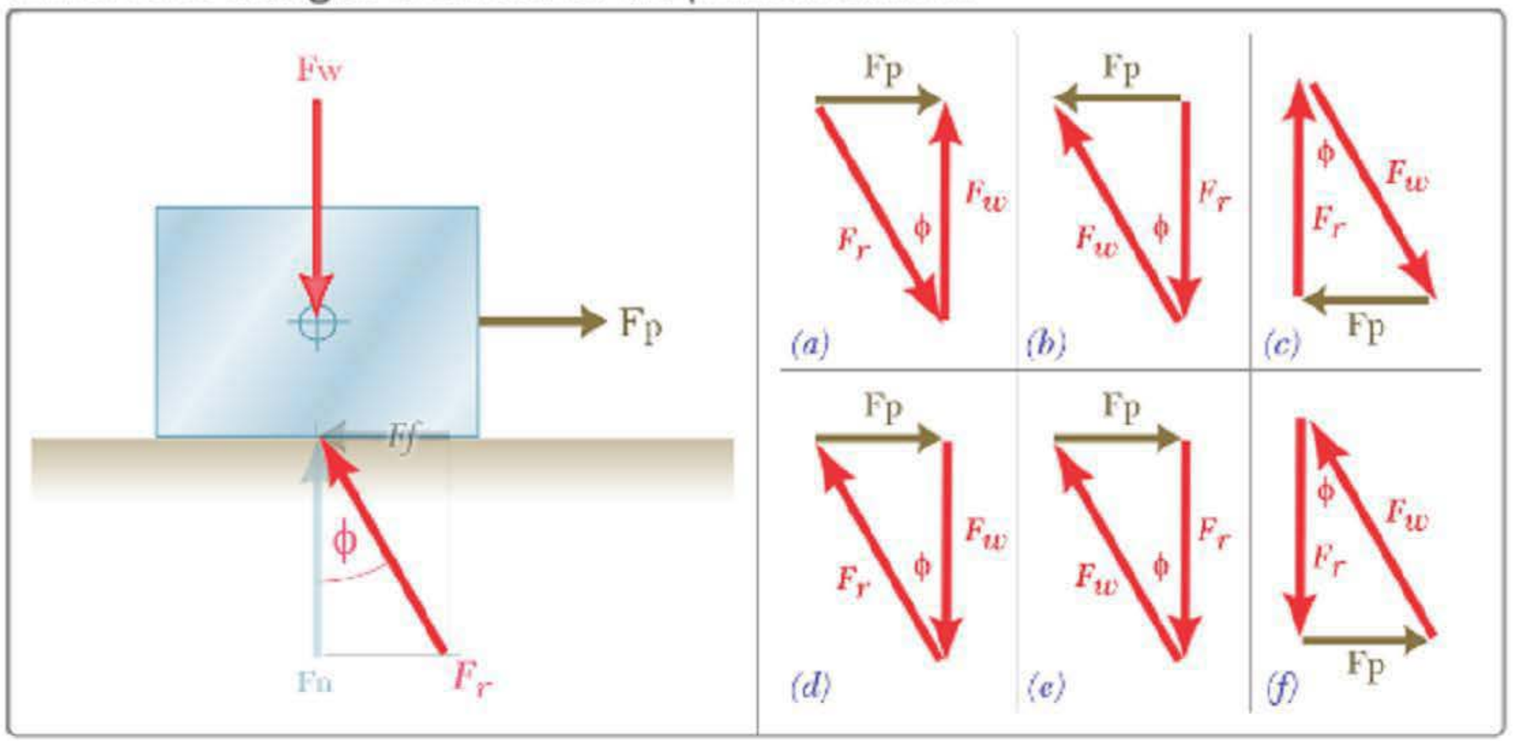


The problem	Weight and angle of friction	Solve for applied force

GIVE FEEDBACK

OK

Which force triangles is correct for the problem shown?



Click the correct answer.

(e)

(f)

(c)

(b)

(d)

(a)

The angle of repose is the steepest slope an object can withstand before it begins to slide.

Angle of repose

The angle of repose is the angle at which the object begins to slide.

Video object isn't supported in c++ version

This is directly related to the coefficient of friction between the two surfaces, and is an easy way to measure it.

However, in practice, once the static friction is overcome, the block will tend to accelerate down the incline. This is because the static coefficient of friction is higher than the kinetic coefficient.

The angle that allows the object to travel downhill at constant speed would give the kinetic coefficient of friction.

GIVE FEEDBACK

OK

The object begins to slide when the inclination of the plane exceeds ____.

Video object isn't supported in c++ version

Click the correct answer.

- the angle of repose
- the angle of friction
- the angle of inclination
- 45°

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The angle of inclination is slowly increased until it reaches the angle of repose. As soon as the object starts to move, it then accelerates down the plane. Why?

Click the correct answer.

- The coefficient of kinetic friction is lower than the coefficient of static friction
- The coefficient of static friction is lower than the tangent of the angle of repose
- The coefficient of kinetic friction is higher than the coefficient of static friction
- The coefficient of static friction is higher than the tangent of the angle of repose

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

We can detect the coefficient of friction by tilting the support plane until the object moves.

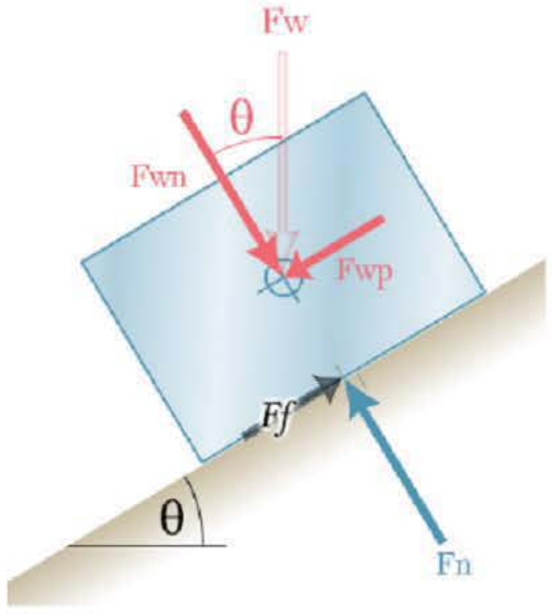
Friction on an inclined plane

There is an easy way to measure the coefficient of friction between two surfaces. Simply tilt the plane up slowly to an angle θ from the horizontal.

The weight of the block F_w can now be resolved into components:

- F_{wp} in line with the plane
- F_{wn} perpendicular to the plane.

If the tilt angle is small, the block will not slide because the force of friction is sufficient for equilibrium.

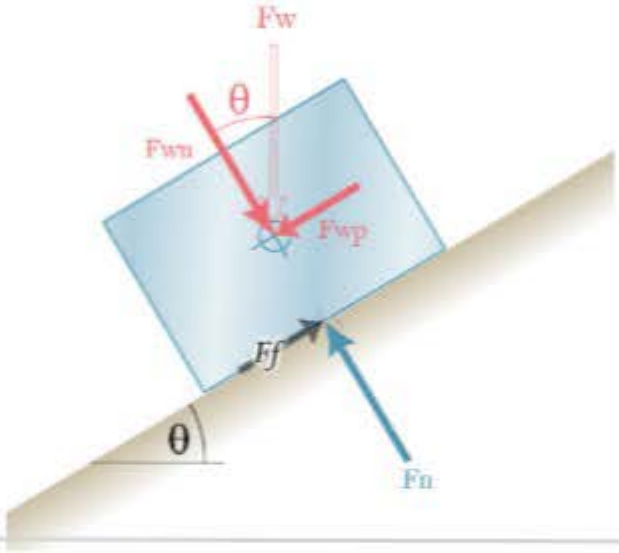


Friction on an inclined plane

GIVE FEEDBACK

OK

This block would begin to slide when ____.

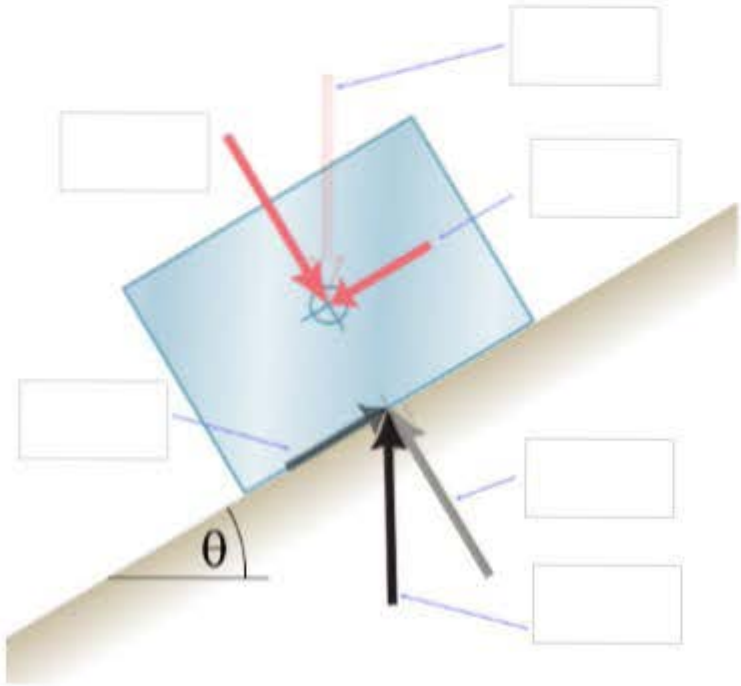


Click the correct answer.

- $F_{wp} > F_f$
- $F_f > F_{wp}$
- $F_{wp} > F_{wn}$
- $F_{wn} > F_n$

Label the free body diagram.

F_w	F_n	F_f
F_r	$F_w \cos \theta$	$F_w \sin \theta$



The angle of repose is a convenient way to find the coefficient of friction.

Use angle of repose to measure the coefficient of friction

As the plane is tilted higher, friction will reach its limit. At this moment, the block is on the point of slipping and all forces are exactly balanced:

Remembering that $\mu = \frac{F_f}{F_n}$, we write:

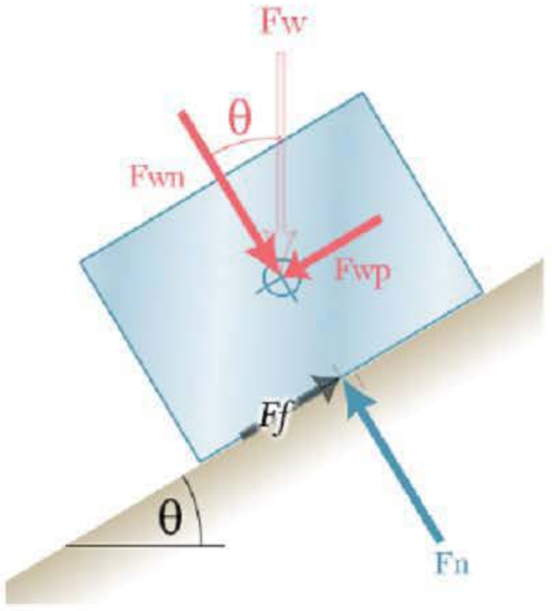
$$\mu = \frac{F_f}{F_n} = \frac{F_w \sin\theta}{F_w \cos\theta} = \tan\theta$$

But since $\mu = \tan\Phi$

$$\therefore \tan\theta = \tan\Phi$$

$$\text{or} \theta = \Phi$$

The angle that has the block at the point of slipping is called the **angle of repose**, which is the same as the angle of static friction.

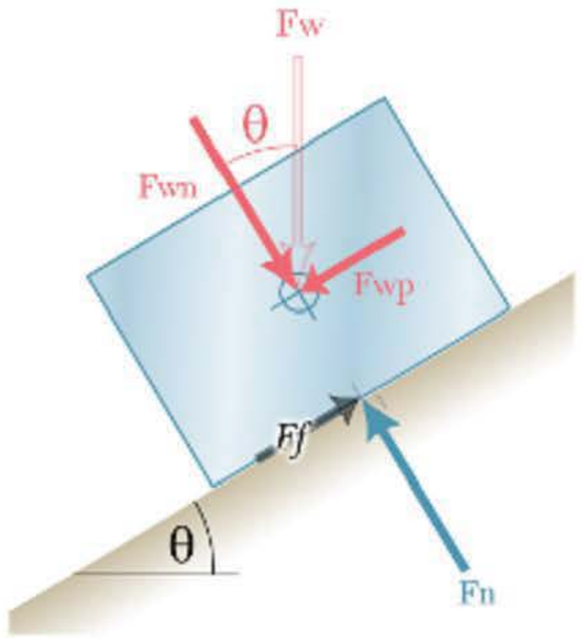


Tilted to the angle of repose

GIVE FEEDBACK

OK

This block is on the verge of sliding. What is the angle of repose?



(Choose all correct answers)

Check all that apply.

- [ ] $\tan \theta$
- [ ] $\tan \mu$
- [ ] $\tan^{-1} \theta$
- [ ] μ
- [ ] θ
- [ ] $\tan^{-1} \mu$

The angle of repose is the point at which slipping starts. This has application to all sorts of inclines, from avalanche risk on mountian sides to the design of grain silos.

Applications of the angle of repose

The **angle of repose** is when slipping starts. This is equal to the angle of static friction.

Understanding the angle of repose is important in the design of bins and hoppers for the storage and handling of granular materials, and for calculating the steepest slope of loose material or an embankment.

Granular materials with a high angle of repose require a steeper cone to prevent clogging of the hopper.

GIVE FEEDBACK

OK

Which of the following are at the angle of repose?

Check all that apply.

- [ ] Steepest icy road a car can drive on
- [ ] The steep side of a sand dune (downwind)
- [ ] Avalanche snow conditions on a mountainside
- [ ] The maximum slope of a coal conveyor

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Calculate the angle of repose--Example

Example

What is the steepest ramp on which a car can stand without slipping down if the coefficient of friction between the tyres and the ramp surface is 0.8?

GIVE FEEDBACK

CONTINUE >

Calculate the angle of repose--Example

Example

What is the steepest ramp on which a car can stand without slipping down if the coefficient of friction between the tyres and the ramp surface is 0.8?

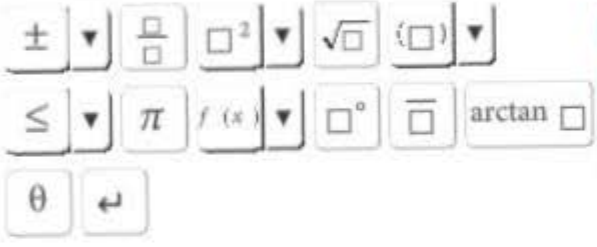
Solution

$$\begin{aligned}\text{Angle of repose} &= \text{angle of friction } \Phi \\ &= \tan^{-1}\mu \\ &= \tan^{-1}0.8 \\ &= 38.7^\circ\end{aligned}$$

< BACK GIVE FEEDBACK OK

What is the steepest incline on which a car can park without slipping down if the coefficient of friction between the tyres and the ramp surface is 0.35?

Do not type the units. Use at least 1 decimal place



Click and type your answer here

CHALLENGE SUBMIT SHOW ANSWER

INSTRUCTIONS

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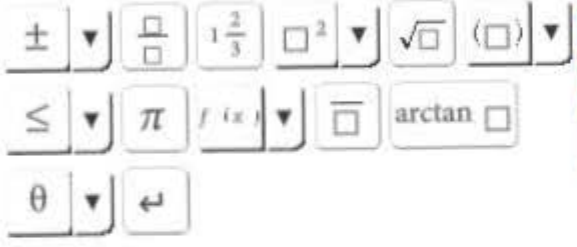
Hint Each hint will reduce the credit received for this question

A ramp is built at a slope of 1 in 8. This means it goes higher by 1 m (rise) for every 8 m of horizontal travel (run). What is the minimum angle of friction required for anything travelling on this ramp?

Do not include units. Use at least 2 decimal places



CHALLENGE SUBMIT SHOW ANSWER

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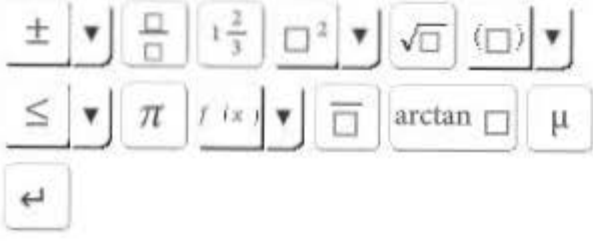
- The computer will check all your work in detail when you click "Submit".

Hint Each hint will reduce the credit received for this question

A ramp is built at a slope of 1 in 8. This means it goes higher by 1 m (rise) for every 8 m of horizontal travel (run). What is the minimum coefficient of friction required for anything travelling on this ramp?

Use at least 3 decimal places



Click and type your answer here

CHALLENGE SUBMIT SHOW ANSWER

INSTRUCTIONS

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Hint Each hint will reduce the credit received for this question

Example

A wet barefoot friction test is carried out for tiles designed for the edges of swimming pools. The tiles must achieve a slip rating of 'C', which, according to Australian Standard 4586, is a slope of 24°.

What is the coefficient of friction?

GIVE FEEDBACK

CONTINUE >

Solution

$$\begin{aligned}\text{Coefficient of friction} &= \tan\theta \\ &= \tan 24^\circ \\ &= 0.445\end{aligned}$$

What is the coefficient of friction between the sole of a shoe and a roof if slippage occurs at an angle of 25 degrees?

Use at least 3 decimal places

Click and type your answer here

CHALLENGE SUBMIT SHOW ANSWER

INSTRUCTIONS

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Hint Each hint will reduce the credit received for this question