Friction
Solid friction

Friction is the forces which oppose the relative motion of two surfaces in contact.

The direction of the friction force is opposite to the direction of motion of the body.

Types of friction

There are 2 types of friction i.e.

(i) Static friction

(ii) Kinetic friction / sliding friction

Static friction opposes the tendency of one body sliding over the other.

Kinetic/sliding/dynamic friction opposes the sliding of one body over the other.

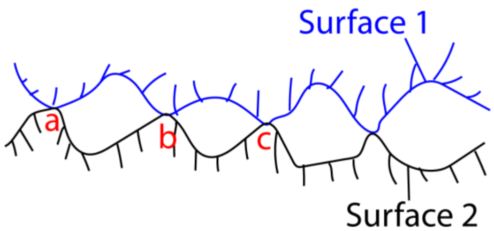
Limiting friction is the maximum friction between on two surfaces.

Laws of solid Friction

1. The frictional force between two surfaces opposes their relative motion.
2. The frictional force is independent of the area of contact of the given surface when the normal reaction is constant.
3. The limiting frictional force is proportional to the normal reaction for case of static friction. The frictional force is proportional to the normal reaction for the case of kinetic (dynamic) friction and is independent of the relative velocity of the surfaces

Molecular Theory and the laws of solid friction

On a microscopic level, even a highly polished surface has bumps and hollow. It follows that when 2 surfaces are put together, the actual area of contact is less than the apparent area of contact.



At points of contact like a, b, c, small cold-welded joints are formed by the strong adhesive forces between the molecules in the two surfaces.

These joints have to be broken before one surface can move over the other.

This accounts for law 1.

The actual area of contact is proportional with the normal force (reaction). The frictional force which is determined by the actual area of contact at the joints is expected to be proportional to the normal force.

This accounts for law 1 and 3

If the apparent area of contact of the body is decreased by turning the body so that it rests on one of the smaller side, the number of contact points is reduced. Since the weight of the body has not altered, there is increased pressure at the contact points and this flattens the bumps so that total contact area and the pressure return to their original values.

Therefore, although the apparent area of contact has been changed, the actual area of contact has not.

This accounts for law 3

Coefficient of static friction

Coefficient of limiting friction is proportional to the normal reaction or it weight.

i.e. $\frac{limiting\ fricitional\ force\ (F)}{normal\ reaction\ (R)} = \mu, a\ constnat$

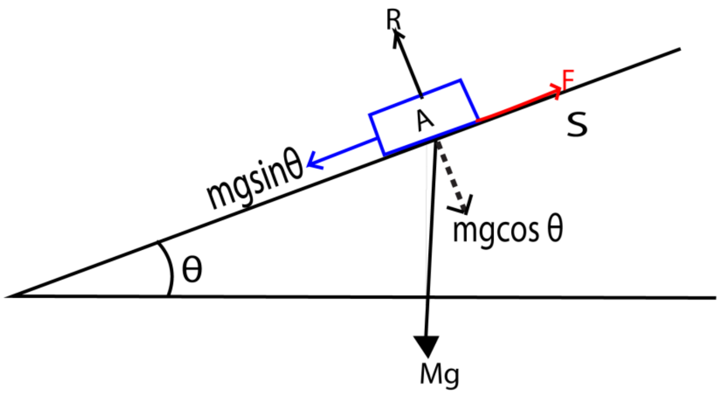
μ is known as the coefficient of friction between the two surfaces. The magnitude of μ depends on the nature of the two surfaces; for example it is about 0.2 to 0.5 for wood on wood, and about 0.2 to 0.6 for wood on metals.

Measurement of coefficient of static friction, μ_s

Method 1: Using a tilting plane.

A block A is placed on a plane and the plane is tilted until when the block begins to slide. The angle of θ of inclination of the plane surface to the horizontal is measured.

The co-efficient of friction is given by $\mu_s = \tan\theta$



When the block is at the point of sliding

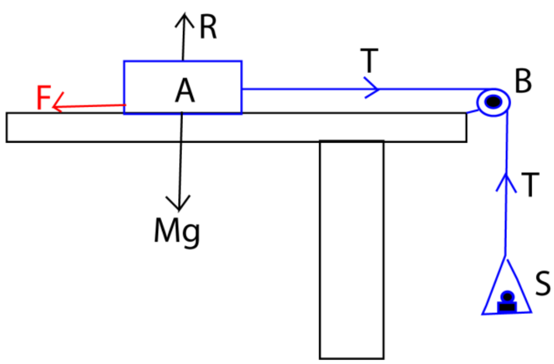
Fs = Wsinθ ………….(i)

R = Wcosθ…………..(ii)

(i) ÷ (ii)

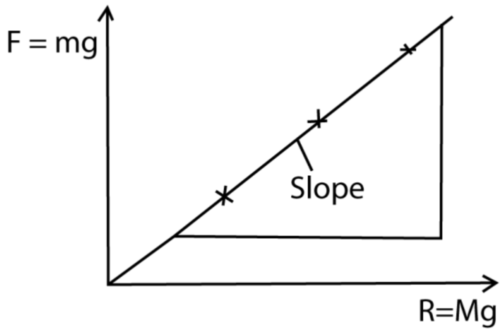
$\frac{Fr}{R} = \frac{W\sin\theta}{W\cos\theta} = \mu_s = \tan\theta$

Method 2: To determine the co-efficient of static friction.



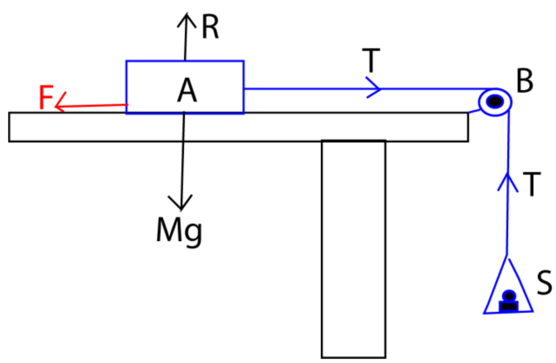
Masses are added to the scale pan until the block just slides. The total mass m of the scale pan and masses added is noted. The procedures are repeated for different values of R obtained by adding known weights to the block.

A graph of mg against R(Mg) is plotted.



The slope of the graph is μ_s

Co-efficient of kinetic (dynamic friction



A wooded block of known weight is connected to a scale pan by a string passing over a smooth pulley as shown in the diagram above.

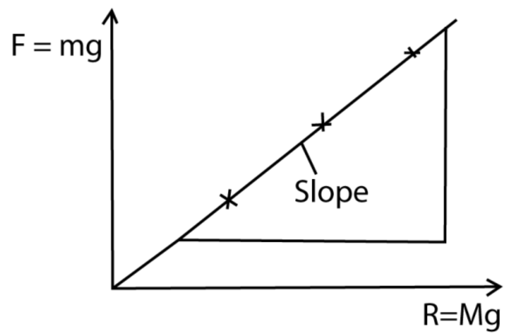
Small masses are added to the scale pan one at a time and each time the block is given a slight push. This is repeated until the block moves with a constant speed after a light push.

At this instant, the weight of the scale pan and all masses added to it is equal to kinetic frictional force (f).

The weight of the block is equal to the normal reaction. the normal reaction is varied by adding known weights on the block at each time finding the corresponding frictional force.

The values of the normal reaction R and corresponding kinetic force (f) is recorded in the table.

A graph of F against R is plotted and its slope gives the coefficient of kinetic friction



The slope of the graph is μs, is coefficient of kinetic friction

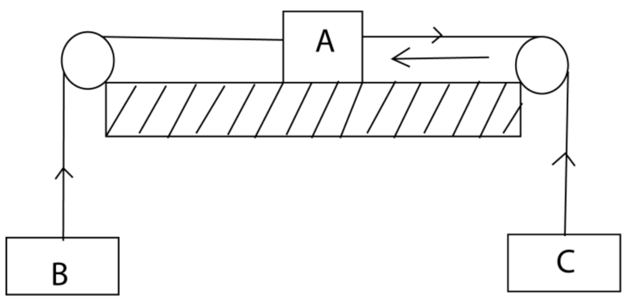
Advantage of friction

- Used in writing
- Used in movement
- Used in walking

Disadvantage of friction

- Wears machines
- Wears shoes
- Causes unnecessary noise in moving parts of a machines.

Examples 1



A, B, C are particles with masses 7, 5, 2kg respectively. when the system is released from rest with coefficient of friction 1/5.

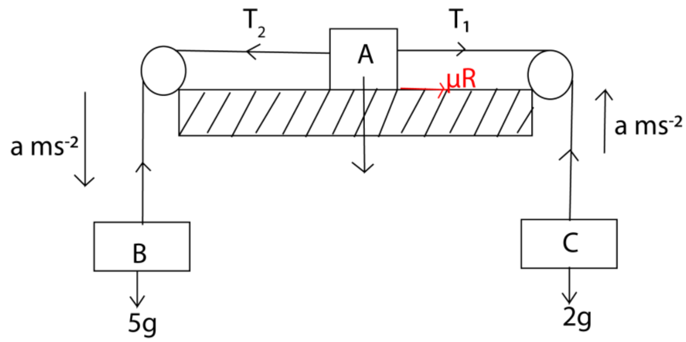
Find

(a) Acceleration of the system

(b) Tension of the strings

(c) Distance moved by B after 4s

Solution



(a) Consider B

$5a = 5g – T_2$ ……………………………..(i)

Consider C

$2a = T_1 - 2g$…………………………… (ii)

Consider A

$7a = T_2 – (T_1 + \mu R)$

But R = 7g

$7a = T2 – T1 - \frac{1}{5}\ x\ 7g$ ……………….. (iii)

Eqn (i) + Eqn (ii) + Eqn (iii)

$5a + 2a + 7a = 5g – T_1 + T_2 – 2g + T_1 - T_2 - \frac{1}{5}\ x\ 7g$

$14a = 1.6g$

$a = \frac{1.6\ x\ 9.81}{14} = 1.12ms^{-2}$

(b) From (i)

$5a = 5g – T_2$

$5 x 1.12 = 5 x 9.81 – T_2$

$T_2 = 43.45N$

From (ii)

$2a = T_1 - 2g$

$2 x 1.12 = T1 – 2g$

$T1 = 21.86N$

(c) $s = ut + \frac{1}{2}at^2$

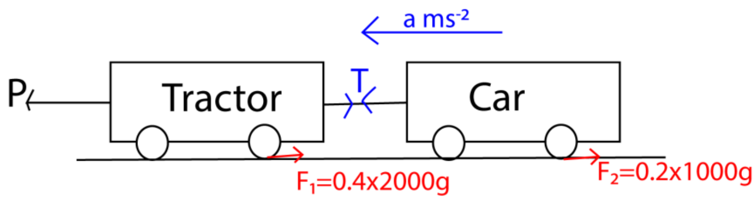
s = 0 x 4 + 1.12 x 4 x 4 = 17.92m

Example2

A tractor of mass 2000kg is used to pull a car of mass 1000kg to which it is connected by a chain whose mass can be neglected. The tractor pulling steadily moves the car from rest along a horizontal road through a distance of 12,5m in 5s. The coefficient of kinetic friction between the tyres of the tractor and the road is 0.4 and that between the tyres of the car and the road is 0.2.

Find the pull exerted by the tractor's engine.

Solution



Consider motion of the tractor

2000a = P- (T + F_1)

= P – T- 0.4x 2000 x 9.81

= P – T – 7848 ……………………………………(i)

Consider motion of the tractor

1000a = T – F_2

= T – 0.2 x 1000 x 9.81

= T – 1962 …………………………………….. (ii)

Eqn (i) + Eqn (ii)

3000a = P – 9810

From s = ut + $\frac{1}{2}t^2$

12.5 = 0 x 5 + $\frac{1}{2}$ x 5 x 5

a = 1ms-2

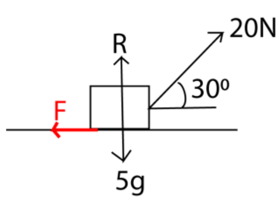
thus, P = 3000 x1 + 9810 = 12810N

Example 3

A body of mass 5kg is at rest on a rough horizontal plane of coefficient of friction of 0.6. a force of 20 N at 300 above the horizontal is applied on the body. Find

(i) normal reaction
(ii) frictional force exerted by the floor on the body.

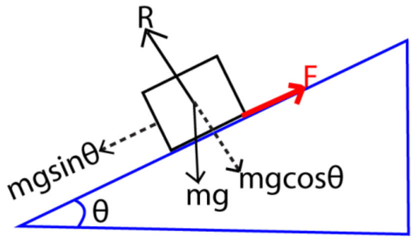
Solution



(i) Resolving vertically
R + 20sin 30^0 = 5g
R = 5 x 9.81 – 10 = 39.05N
(ii) F = μR = 0.6 39.05 = 23.43N

Motion on an inclined plane

(i) When a body is moving down the slope



Resulting force = mgsinθ –F

ma = mgsinθ –F

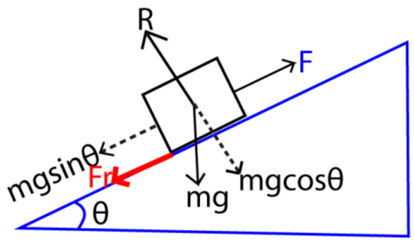
but F = μR

and R = mgcosθ

⇨ ma = mgsinθ –μcosθ

a = g(sinθ –μcosθ)

(ii) when the body is moving up the slope



Resultant force = F + mgsinθ

ma = mgsinθ + F

but F = μR

and R = mgcosθ

⇨ ma = mgsinθ +μcosθ

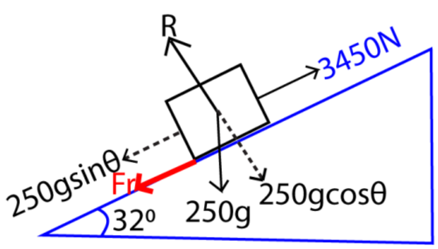
a = g(sinθ + μcosθ)

Example 4

A car of mass 0.25 x 10^3kg ant a tractive pull of 3450N climbs a truck which is inclined at 32^0 to the horizontal. The velocity of the car at the bottom of the inclined plane is 27ms^{-1} and the coefficient of friction between the plane and the car tyres is 0.25. Calculate

(a) distance travelled along the inclined before the car comes to rest.
(b) Time taken before the car comes to rest

Solution



(a) From $ma = F - (f + mg\sin\theta)$, $f = \mu R = \mu mg\cos 32^0$

$250a = 3450 - (0.25 \times 250 \times 9.81\cos 32^0 + 250 \times 9.81\sin 32^0)$

$a = 6.52ms^{-2}$

From $v^2 = u^2 - 2as$

$0 = 27^2 - 2 \times 6.52s$

$s = 55.9m$

from $v = u - at$

$0 = 27 - 6.52t$

$t = 4.15s$

Exercise

1. A car of mass 200kg moving along a straight road at a speed of $96kmh^{-1}$ is brought to rest by steady application of the brakes in a distance of 80m. Find the co-efficient of kinetic friction between the tires and the road. [hint $ma = \mu mg$; $\mu=0.45$]

2. A car of mass 1.5×10^3kg and tractive pull 3.5×10^3N climbs a truck which is inclined at an angle of 30^0 to the horizontal. The speed of the car at the bottom of the incline is $20ms^{-1}$ and the coefficient of sliding friction is 0.25, calculate
   (i) The distance travelled along the incline before the car comes to a halt.
   (ii) The time taken travelling along the incline before the car comes to a halt.
   [Ans. s = 42.6m, t = 4.26s]

3. An old car of mass 1500kg and tractive pull 4000N climbs a tract which is inclined at an angle of 30^0 to the horizontal. The velocity of the car at the bottom of the incline is $108kmh^{-1}$ and the coefficient of sliding friction is 0.35.
   (i) Calculate the distance travelled along the incline before the car comes to a halt.(86.53m)
   (ii) The time taken to travel along the incline before the car comes to a halt.(5.77s)

4. In an experiment to determine the coefficient of static friction between a block and a plane, a student placed the block on a wooded surface and tilted the surface until the block just began to move. He observed that this happened at an angle of inclination of the plane with the horizontal of 20^0 and the block slid 100cm down the plane in 2s. Calculate the coefficient of static friction. [$\mu = 0.31$]

5. Two masses m_1 and m_2 rests on a rough faces of a double inclined plane and connected by a light inextensible string passing over a pulley at the top of the plane. If m1>m2, show that acceleration of the system $a = \frac{g[m_1(\sin\alpha - \mu\cos\alpha) - m_2(\sin\beta + \mu\cos\beta)]}{(m_1 + m_2)}$, where α and β are angles of inclination for plane on which m_1 and m_2 are place respectively

6. (a) (i) State the laws of solid friction

   (ii) With the aid of a well labeled diagram describe an experiment to determine th e coefficient of kinetic of kinetic friction between the two surfaces.

   (b) A body slides down a rough plane at 300 to the horizontal. If the coefficient of kinetic friction between the body and the plane is 0.4. Find the velocity after the body has travelled 6m along the plane.[4.2521ms^{-1}]

7. (a)(i) State the laws of friction between solid surfaces

   (ii) Explain the origin of friction force between two solid surfaces in contact.

   (iii) Describe an experiment to measure the coefficient of kinetic friction between two solid surfaces

   (b) (i) A car of mass 100kg moves along a straight surface with a speed of 20ms-1. When brakes are applied steadily, the car comes to rest after travelling 50m. Calculate the coefficient of friction between the surface and the tyres. [μ =0.4077]

   (ii) State the energy changes which occur from the time the brakes are applied to the time to the time the car comes to rest.

   [kinetic energy →heat → sound energy]

   (c)(i) State the disadvantages of friction

   [Wears tyres, produces unnecessary noise]

   (ii) Give one method of reducing friction between solid surface.[by lubrication]

8. A block of mass 6.0kg is projected with a velocity of 12ms^{-1} up a rough plane inclined at 45^0 to the horizontal. It travels 5.0m up the plane. Find the frictional force. [44.8N]

9. (a) state the laws of friction

   (b) A block of mass 5.0kg resting on the floor is given horizontal velocity of 5.0ms^{-1} and comes to rest in a distance of 7.0m. Find the coefficient of kinetic friction between the block and the floor.

   (c) A car of mass 1500kg rolls from rest down a road inclined to the horizontal at an angle of 35^0, through 50m. The car collides with another car of identical mass at the bottom of incline. If the two vehicles interlock on collision and coefficient of kinetic friction is 0.20, find the common velocity of the vehicles [v = 10.024ms^{-1}]