**SENIOR FIVE TERM 1**

**TOPIC 6/6: SOLID FRICTION**

**Competency:** The learner investigates factors that determine solid friction and its effect on static and dynamic systems, and uses this concept to model efficient systems with minimised friction.

## Frictions

**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

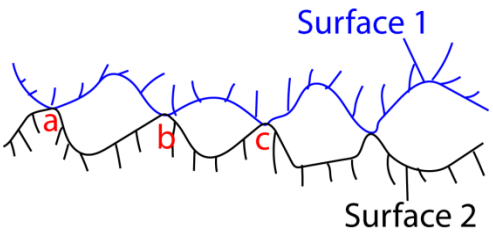
(i) The frictional force between two surfaces opposes their relative motion.

(ii) The frictional force is independent of the area of contact of the given surface when the normal reaction is constant.

(iii) 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

- For any two solid surfaces in contact, there are small humps and hollows that form contact points a, b c ……




- Therefore, the actual area of contact is indeed small which creates very high pressure at the points of contact.
- This pushes the molecules very close that the forces of attraction between them weld the surfaces at these points.
- Thus, a force that opposes motion in any direction is created.

**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.

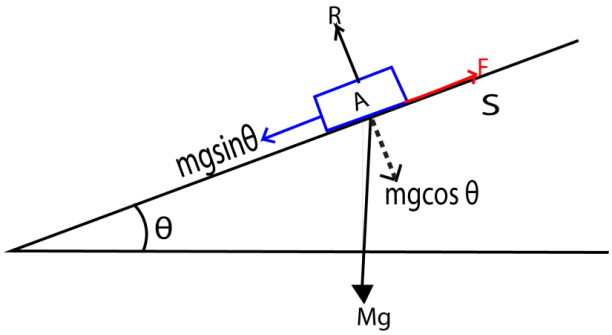
**Measurement of coefficient of static friction, μs**

***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

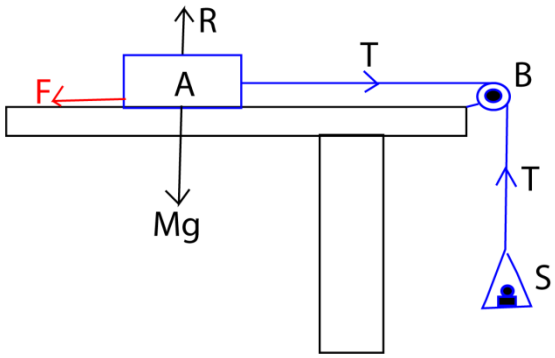
Fr = Wsinθ .....(i)

R = Wcosθ.....(ii)

(i) and (ii)

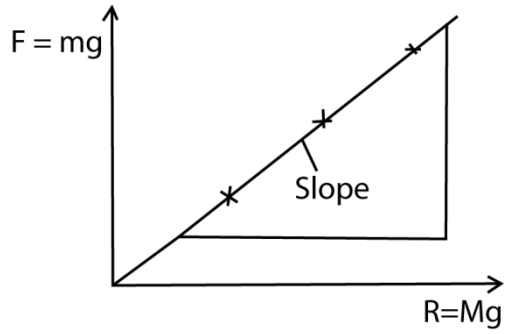
$$\frac{Fr}{R} = \frac{Wsin\,\theta}{Wcos\,\theta} = \mu_s = \tan\theta$$

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



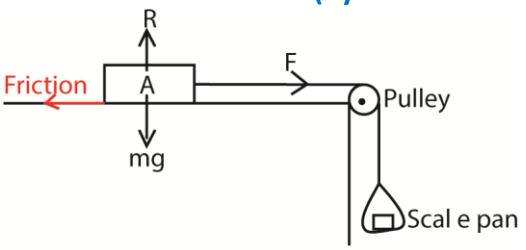

Masses are added to the scale pan until the block just slides. The total mass m of the scale pan and masses added is noted. The procedures are repeated for different values of R obtained by adding known weights to the block.

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




The slope of the graph is $\mu_s$

## Co-efficient of kinetic (dynamic friction)

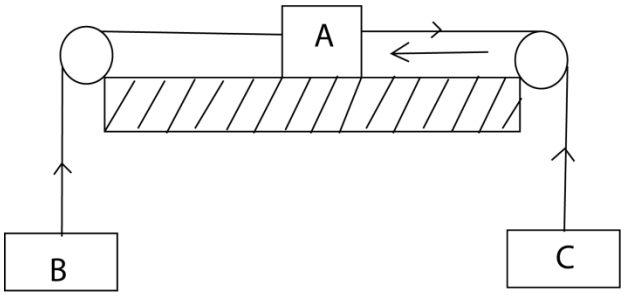



- A block A of mass m is placed on a flat table and connected to a scale pan as shown in the diagram above.
- Weights are added to the scale-pan, and each time A is given a slight push.
- At one stage A continues to move with a constant velocity.
- The coefficient of kinetic friction, $\mu = \frac{W_f}{mg}$; where $W_f$ = weight of the scale pan plus added weights.

Advantage of friction
- Used in writing
- Used in lighting match stick
- Used in walking
- Gripping objects
- Generating heat by rubbing hands
- Car brakes

Disadvantage of friction
- Wears machines
- Wears shoes
- Causes unnecessary noise in moving parts of machines.
- Overheating in moving parts of machines
- Fire risks

### 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.

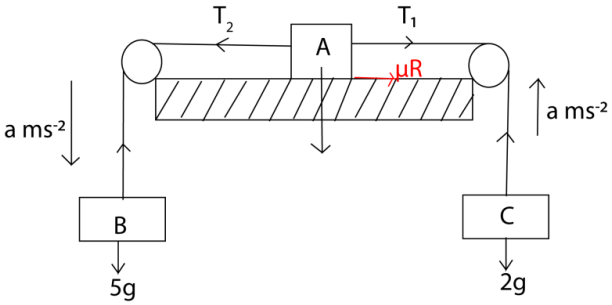
Find

(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 $R = 7g$

$7a = T_2 - T_1 - \frac{1}{5} x\ 7g$ ..... (iii)

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

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

$14a = 1.6g$

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

(b) From (i)

$5a = 5g - T_2$

$5 \times 1.12 = 5 \times 9.81 - T_2$

$T_2 = 43.45N$

From (ii)

$2a = T_1 - 2g$

$2 \times 1.12 = T_1 - 2g$

$T1 = 21.86N$

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

$s = 0 \times 4 + \frac{1}{2} \times 1.12 \times 4^2$

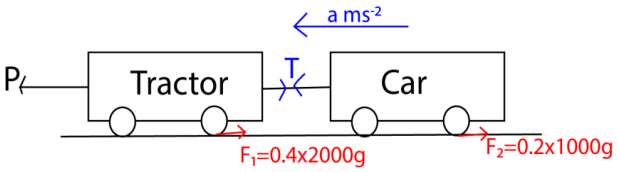
$= 8.96m$

## 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 is 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

$2000a = P - (T + F_1)$

$= P - T - 0.4 \times 2000 \times 9.81$

$= P - T - 7848$ .....(i)

Consider motion of the car

$1000a = T - F_2$

$= T - 0.2 \times 1000 \times 9.81$

$= T - 1962$ ..... (ii)

Eqn. (i) + Eqn. (ii)

$3000a = P - 9810$

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

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

$a = 1 ms^{-2}$

thus,

$P = 3000 \times 1 + 9810 = 12810N$

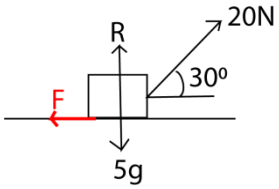
## Example 3

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 $30^0$ 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

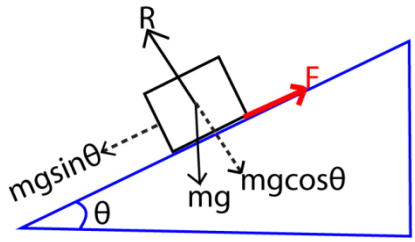
$R + 20\sin 30^0 = 5g$

$R = 5 \times 9.81 - 10 = 39.05N$

(ii) $F = \mu R = 0.6\ 39.05 = 23.43N$

**Motion on an inclined plane**

(i) When a body is moving down the slope




Resulting force = $mg\sin\theta - F$

$ma = mg\sin\theta - F$

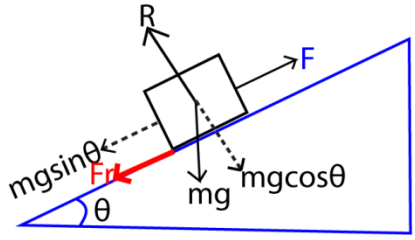
but $F = \mu R$

and $R = mg\cos\theta$

⇨ $ma = mg\sin\theta - \mu\cos\theta$

$a = g(\sin\theta - \mu\cos\theta)$

(ii) when the body is moving up the slope




Resultant force = $F + mg\sin\theta$

$ma = mg\sin\theta + F$

but $F = \mu R$

and $R = mg\cos\theta$

⇨ $ma = mg\sin\theta + \mu\cos\theta$

$a = g(\sin\theta + \mu\cos\theta)$

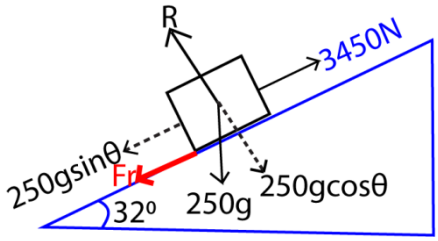
**Example 4**

A car of mass $0.25 \times 10^3$kg and 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 $v = u - at$

$0 = 27 - 6.52t$

$t = 4.15s$

**Methods for reducing friction**

- **Lubrication:** Applying a lubricant like oil, grease, or graphite between surfaces

creates a film that separates them, reducing friction.

- **Polishing surfaces:** Smoothing rough surfaces through polishing or other treatments reduces the interlocking of microscopic irregularities, which lowers friction.
- **Using ball bearings or rollers:** Placing ball bearings or rollers between moving parts converts high-friction sliding motion into much lower-friction rolling motion.
- **Streamlining:** Shaping objects like cars, airplanes, and boats with a streamlined design reduces drag, which is a form of friction caused by air or water.
- **Using low-friction materials:** Employing materials with a naturally low coefficient of friction, such as Teflon, can significantly reduce friction.
- **Reducing contact area:** Decreasing the contact area between surfaces can also reduce friction, for example, by using sharp objects that have a smaller point of contact.

## 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 = μmg; μ=0.45]
2. A car of mass 1.5 x 10$^{3}$kg and tractive pull 3.5x10$^{3}$N 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. [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. [μ = 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 the coefficient of kinetic of kinetic friction between the two surfaces.

   (b) A body slides down a rough plane at $30^0$ 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.[4.2521$ms^{-1}$]
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 12$ms^{-1}$ 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 5.0$ms^{-1}$ 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 = 10.024$ms^{-1}$]

**Thank you**
**Dr. Bbosa Science**