FRICTION

A force that opposes motion

Objectives...

- Explain why friction occurs.
- List the two types of friction, and give examples of each type.
- Explain how friction can be both harmful and helpful.

Today's topics

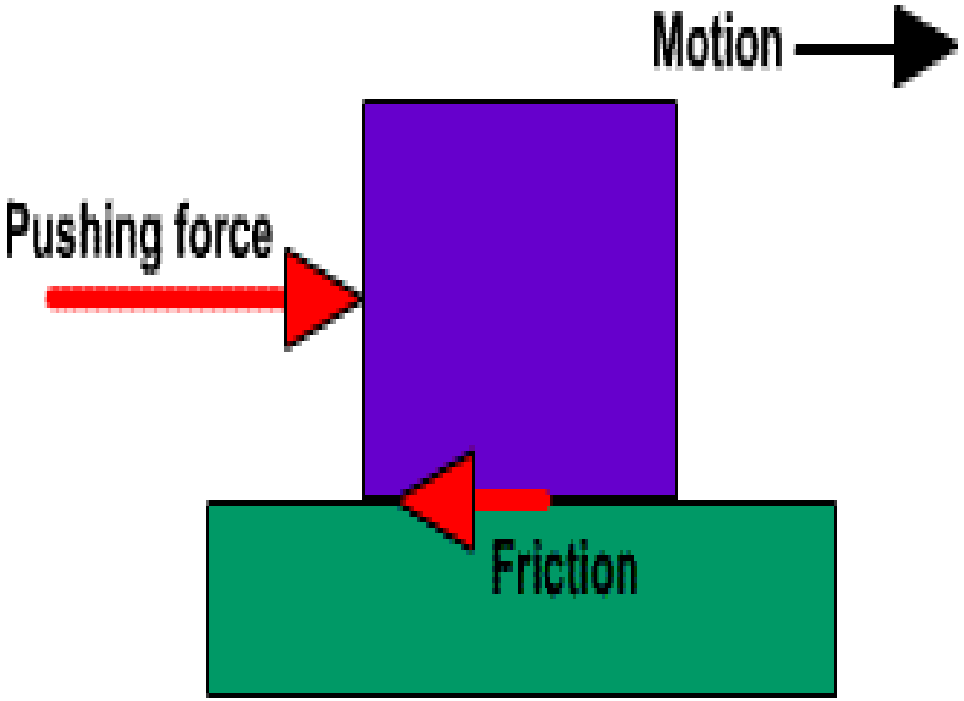
1.THEORY OF FRICTION
2. TYPE OF FRICTION
3. APPLICTION OF FRICTION

What is friction?

- Is a force that opposes motion between two surfaces that are in contact

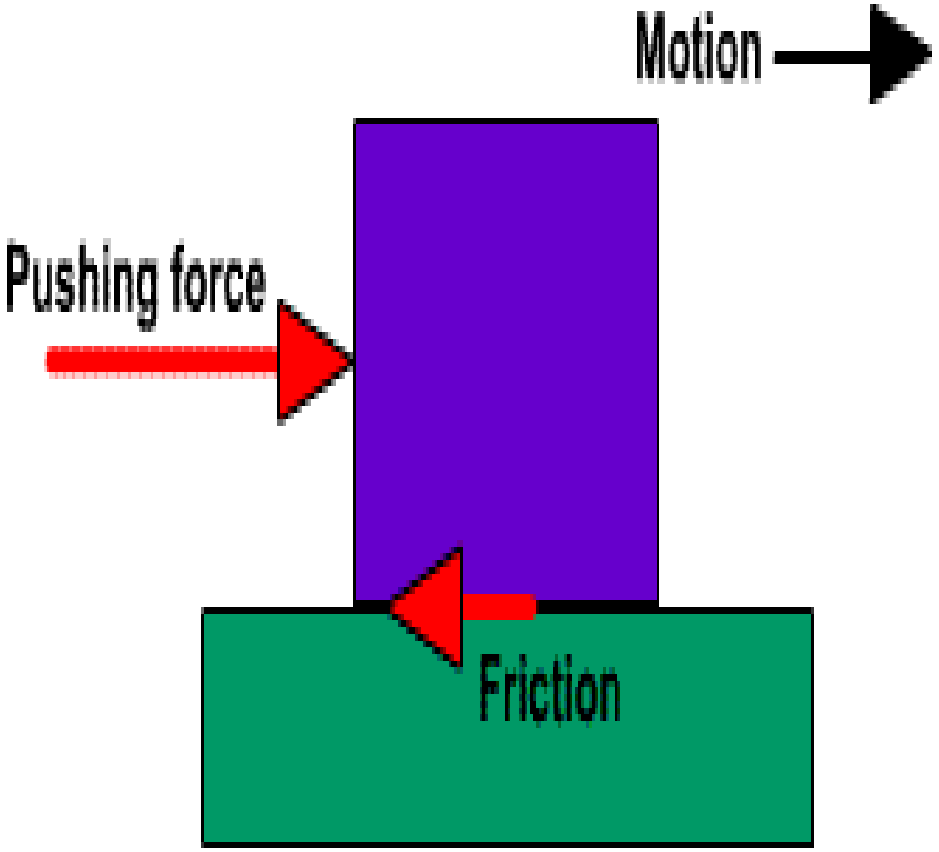
Definition of Friction

"The opposing force, which acts in the opposite direction of the movement of the upper Body ,is called "FRICTION FORCE", or simply " FRICTION ".



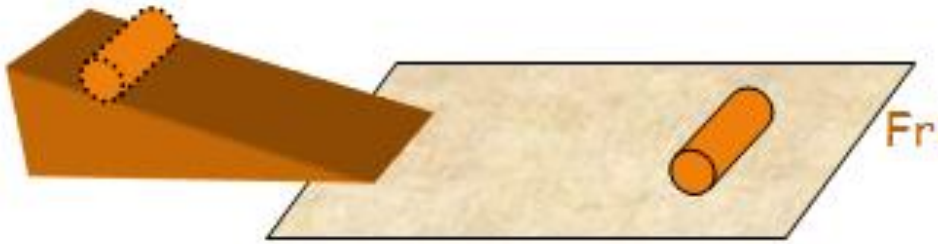
When does friction occur?

- **Friction occurs when two surfaces are in contact**

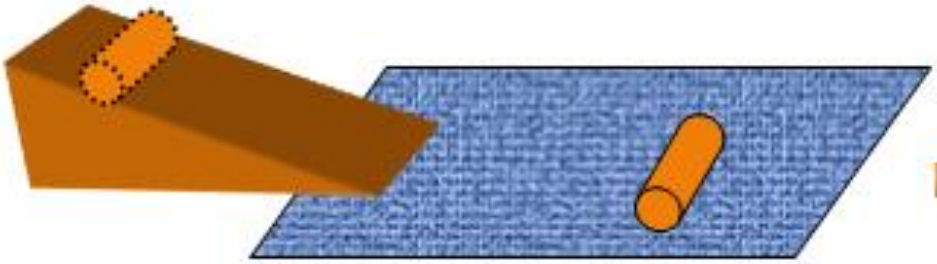


Factors That Affect Friction

- *Roughness of the surface*
- *Force that objects are being pressed one against the other; or their weights*
- Nature of the surfaces in contact. (The smoothness of the surfaces).

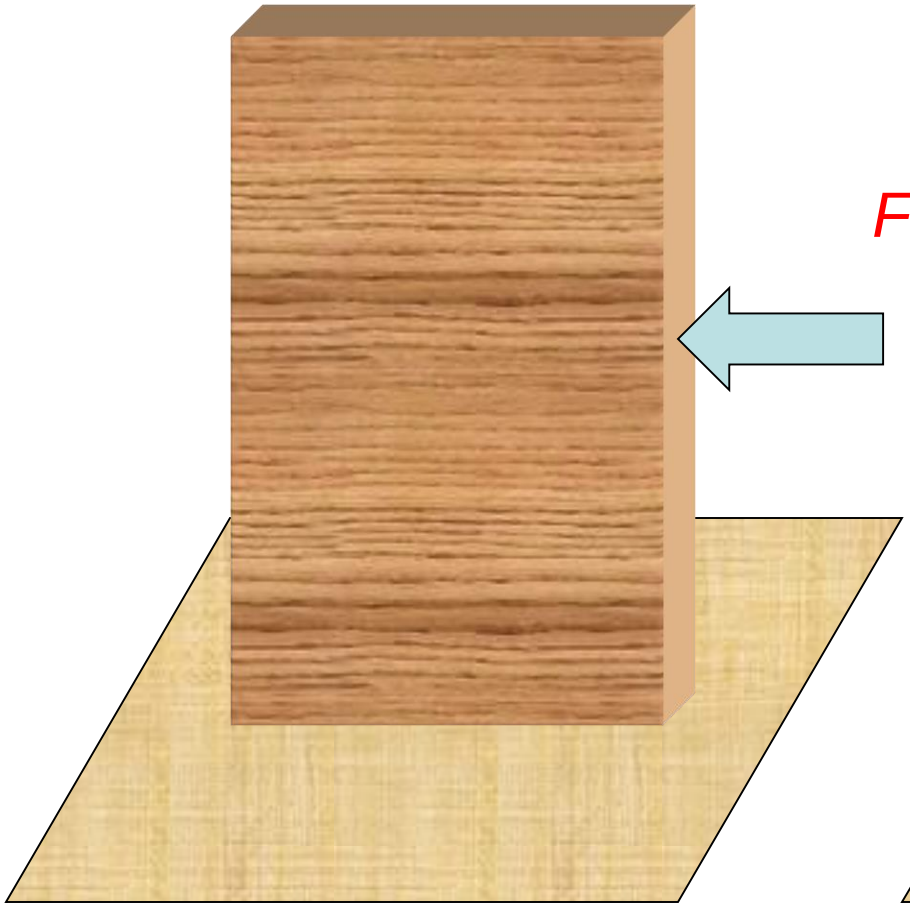


Friction is less on a smooth surface.

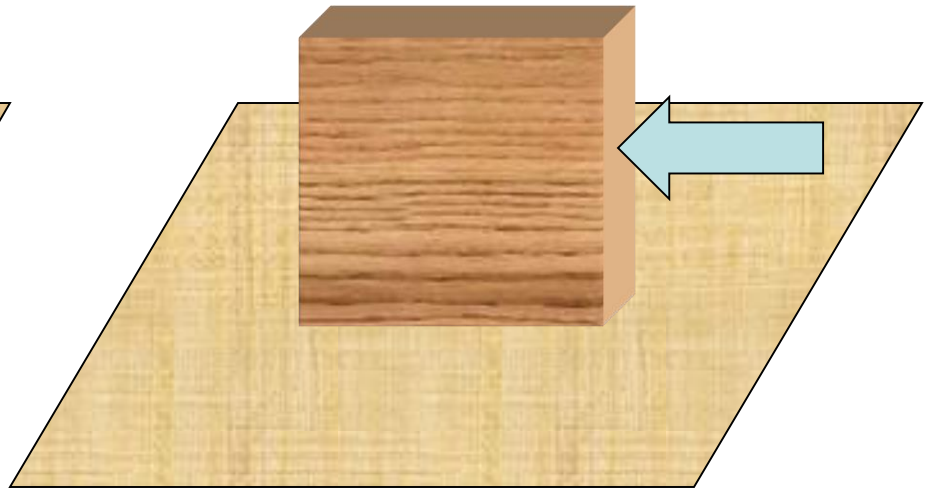


Friction is more on a rough surface

Friction is more if the surfaces are pressed harder.



Friction is less if the surfaces are not pressed harder.

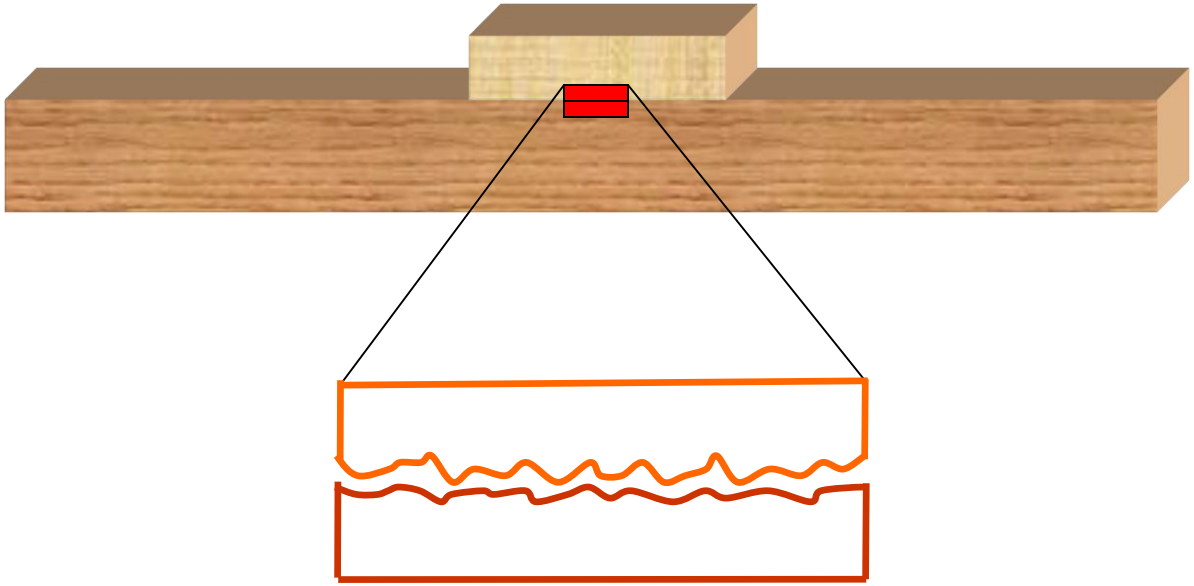


What increases friction?

- Rough surfaces
- And weight of objects

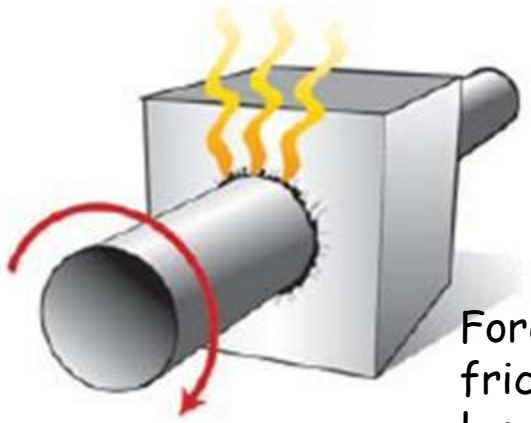
CAUSE OF FRICTION

- *Friction is caused due to the interlocking of irregularities between the two surfaces in contact.*
  - ***Smooth surfaces*** have minute irregularities between the two surfaces.
  - ***Rough surfaces*** have larger irregularities between the two surfaces.
- *So force of friction is more if the surfaces are rough.*

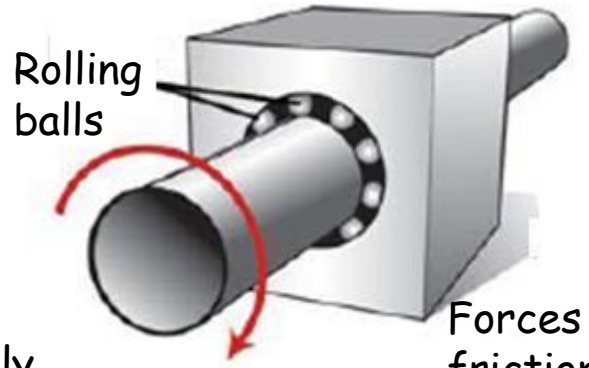


Reducing the force of friction

- Unless a force is constantly applied, friction will slow all motion to a stop eventually.
- It is impossible to completely get rid of friction, but it can be reduced.
  - The friction between a shaft (the long pole in the picture) and an outer part of a machine produces a lot of heat.
  - Friction can be reduced by placing ball bearings between the shaft and the outer part.



Forces from sliding friction are relatively large



Forces from rolling friction are much smaller

Reducing friction

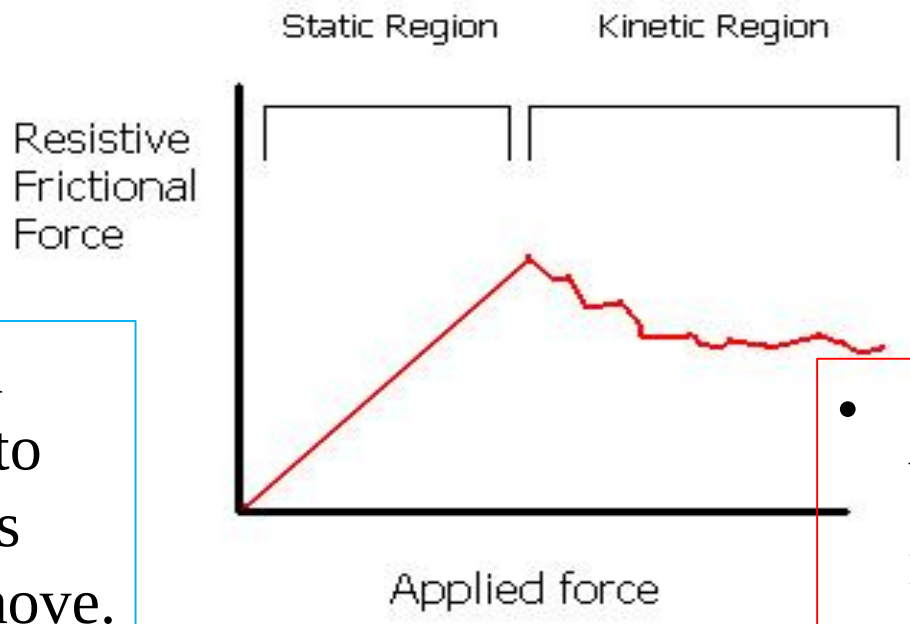
Friction can be reduced by :-

- Using lubricants like powders or oils and grease.
- Using rollers or wheels.
- Using ball bearings.

- We sprinkle powder on a carrom board to reduce friction.
- Oil or grease is applied between moving parts of machines to reduce friction.
- Wheels are used in vehicles to reduce friction.
- Ball bearings are used in ceiling fans, bicycles and vehicles to reduce friction.

TWO TYPES OF FRICTION

- Static – Friction that keeps an object at rest and prevents it from moving
- Dynamics/Kinetic – Friction that acts during motion



- It occurs when a force is applied to an object but this object doesn't move.

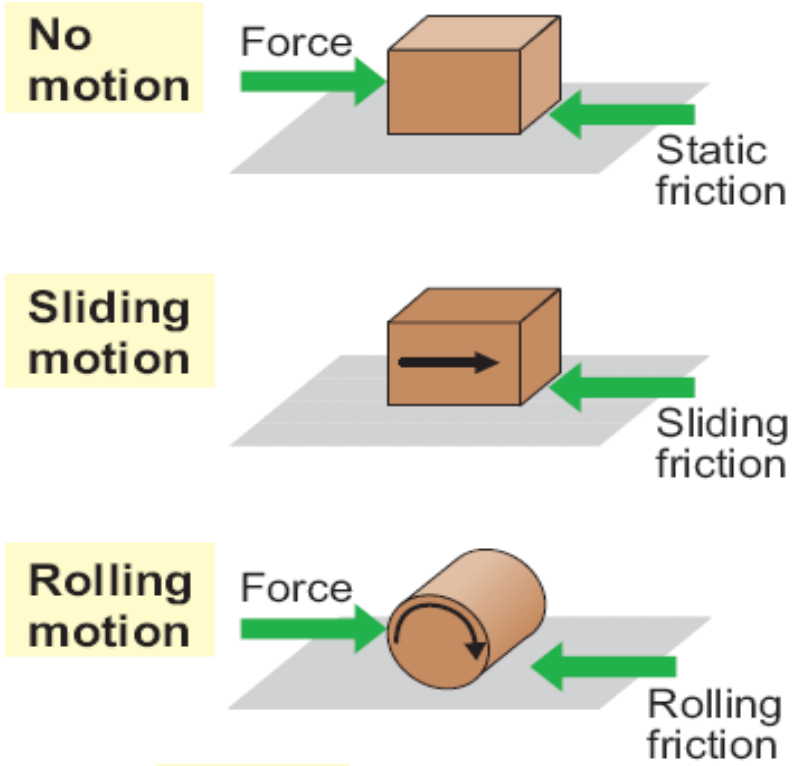
- Is the friction between two moving surfaces

Dynamic friction is also classified into three categories

(i) sliding friction

(ii) Rolling friction

(iii) Pivot friction



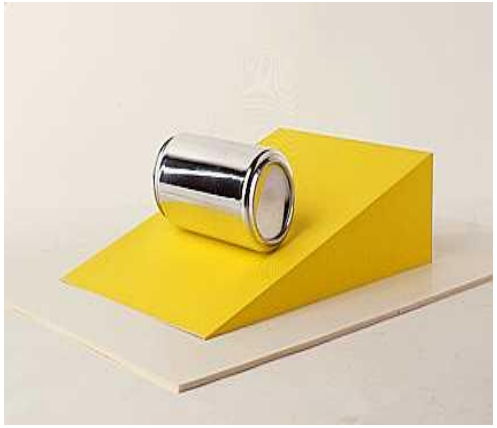
The friction force experienced by a body , due to the motion of rotation as in case of foot step bearings.

IDENTIFYING FRICTION FORCES

- Friction is a force, measured in newtons just like any other force.
  - **Static friction** keeps an object at rest from moving.
  - **Sliding friction** is a force that resists the motion of an object moving across a surface.
  - **Rolling friction** is the friction exerted when an object rolls over a surface.

Static friction


Sliding friction


Rolling friction

SOME OTHER TYPES OF FRICTION

(i) Dry friction - Friction between two un -lubricated or dry surface.

(ii) Lubricated friction - Friction between two lubricated surface.

Lubricated friction can also be classified into two categories –

(a) Greasy friction - when there is a very thin layer of lubricant between the surfaces.

(b) Fluid friction : - when we introduce a thick layer of lubricant between two moving surfaces

- **Skin friction** is a component of drag, the force resisting the motion of a fluid across the surface of a body.

- **Internal friction** is the force resisting motion between the elements making up a solid material while it undergoes deformation.

LAWS OF STATIC FRICTION

i. The applied force will be equal in magnitude with friction force.

ii. The ratio of the limiting friction force to the normal reaction force is called coefficient of static friction.

iii. The force of friction is dependent on the roughness of the surface but independent on the area of contact.

LAWS OF DYNAMIC FRICTION

i. The direction of the friction force will be opposite to the direction of motion of the body.

ii. The ratio of the dynamic friction to the normal reaction is a constant.

iii. As we increase the speed of the moving body then the friction force decrease.

LAWS OF SOLID FRICTION

i. The force of friction is dependent on the material of the surface but independent on the relative velocity of the sliding body and area of contact surface.

ii. The friction force is directly proportional to the normal reaction force.

LAWS OF FLUID FRICTION

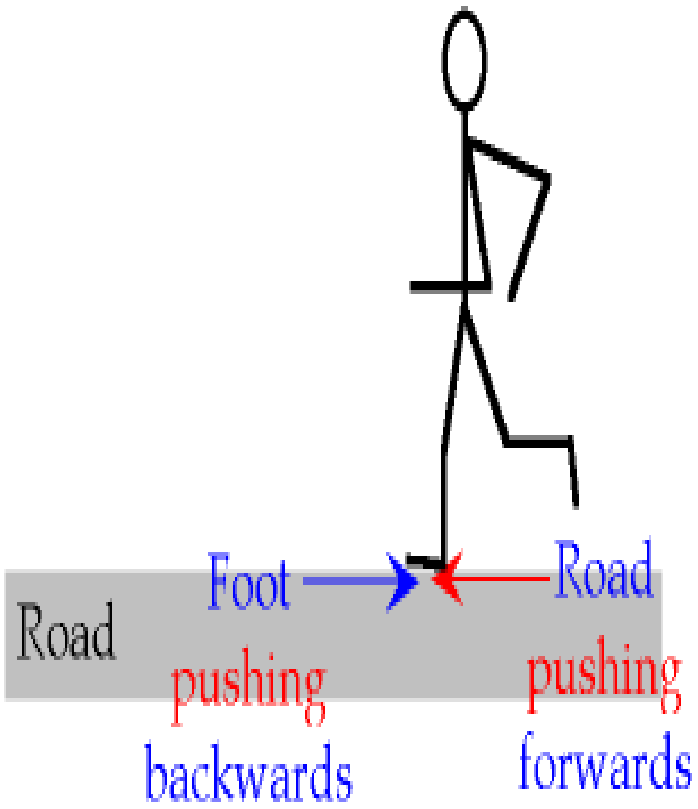
i. The friction force is different for different lubricants.

ii. The friction force is independent on the load as well as substances of the bearing surfaces.

iii. The friction force reduce with increasing in the temperature of the lubricant.

Is friction good or bad?

- **Friction can be good.**
  When we walk we push backwards against the ground,
  the opposing force pushes us forwards.
  Without friction our feet would slip and walking would be impossible.



It is also good

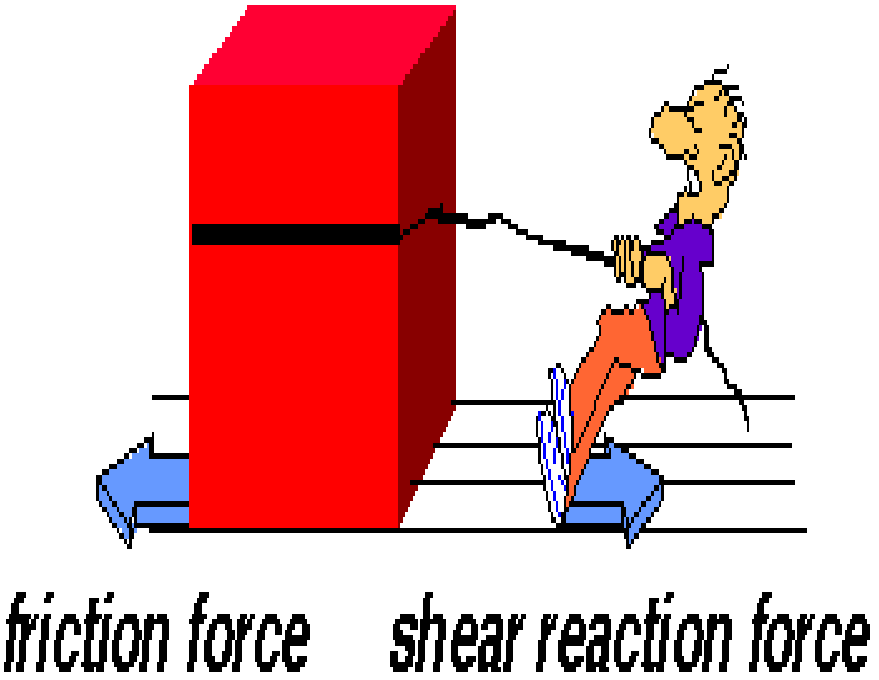
- To stop your bicycle (brake system)

But sometimes is bad…

- Soil erosion caused by wind (friction of a fluid).
- Holes in your shoes, jeans. (friction of a solid) high friction
- Lack of friction is dangerous too, you may fall if the floor is very slippy.

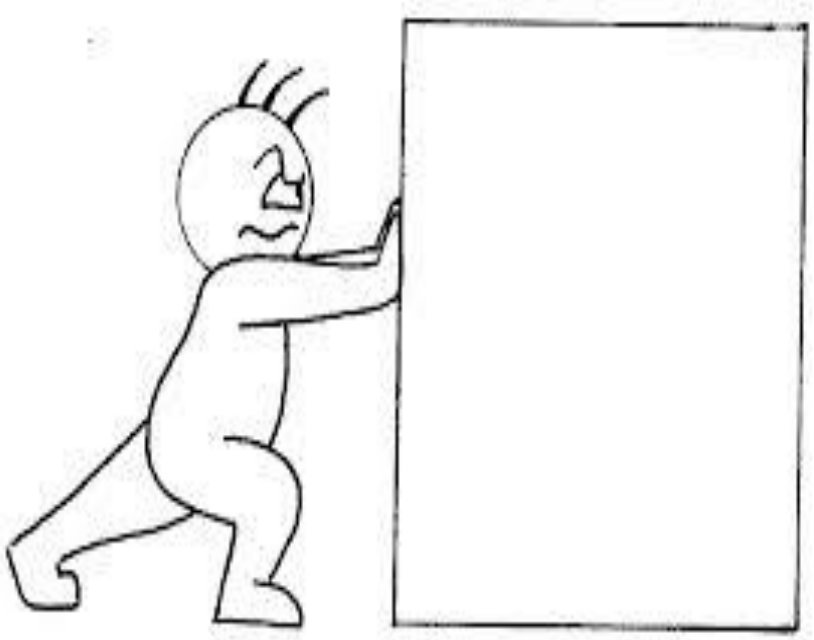
WHERE FRICTION IS DESIRABLE

- During walking on the road.
- In writing on the paper.
- To hold or grabbing something.



WHERE FRICTION IS NOT DESIRABLE

- During walking we have to put extra effort.
- Due to friction the life of the machine part reduced.
- it is not required in mechanical parts where two parts of machine meet.

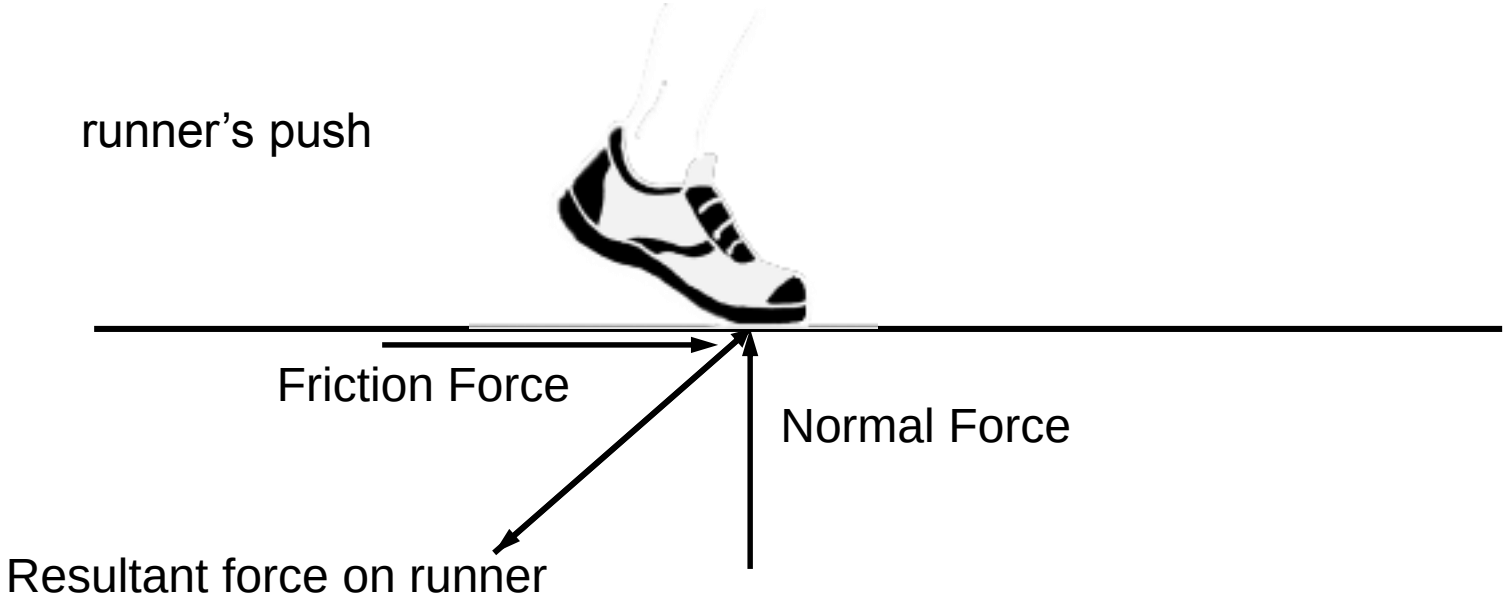


A large effort required to move this block than on a smoother one.

Contact Force

- Force that occurs between objects that are in contact with each other.
- Contact forces can be resolved into components that are perpendicular and parallel to the surfaces in contact.
- The perpendicular component is called the **normal force**.
- The parallel component is called **friction**.

Contact Force in Running



During the push off phase in running, the **normal** force acts upward on the runner, while the **friction** force acts forward on the runner. The friction force is the only force capable of moving the runner horizontally down the track. The normal force can only accelerate the runner upwards.

Advantages of Friction

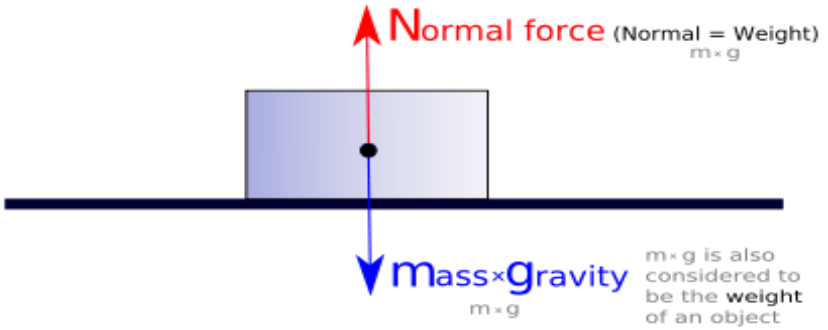
- Friction between pen and paper enables us to write on the paper.
- Friction between our feet and the ground allows our movements like standing, walking and running
- Friction between the surface of the road and tyres of our vehicles allow the vehicles to move without slipping

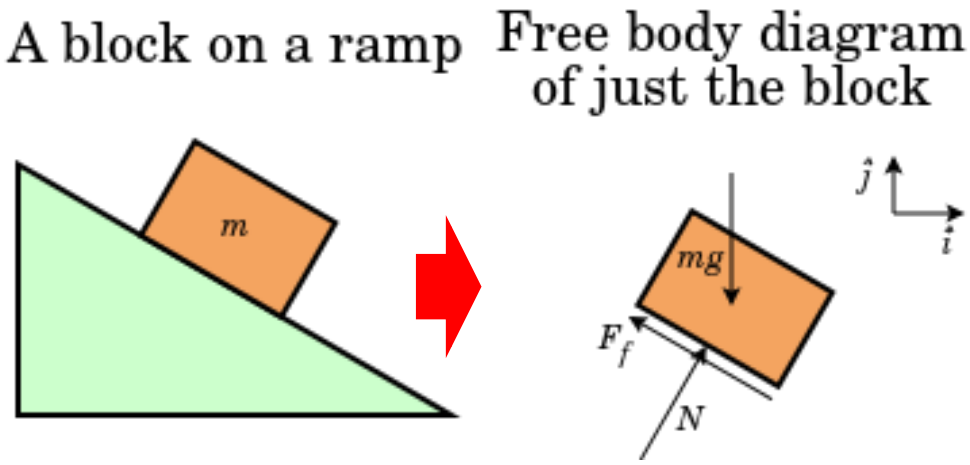
Disadvantages of Friction

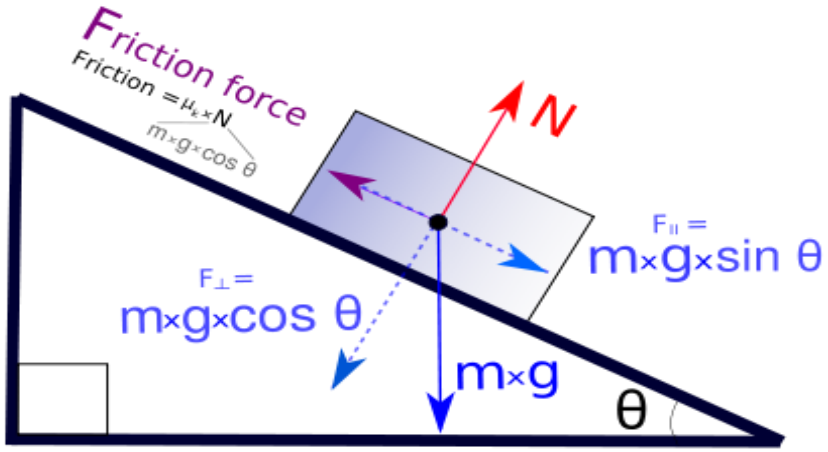
- Friction causes moving objects to stop or slow down.
- Friction produces heat causing wastage of energy in machines
- Friction causes wear and tear of moving parts of machinery, soles of shoes, etc

NORMALREACTION/FORCE

- It is the net force compressing two parallel surface together and the direction of the reaction force will be perpendicular to the surface on which its act.







COEFFICIENT OF FRICTION

- "It is defined as of the ratio of the limiting friction force to the normal reaction force".

- It is represented by the "μ".

- it is given by -> $\mu = F / Fn$

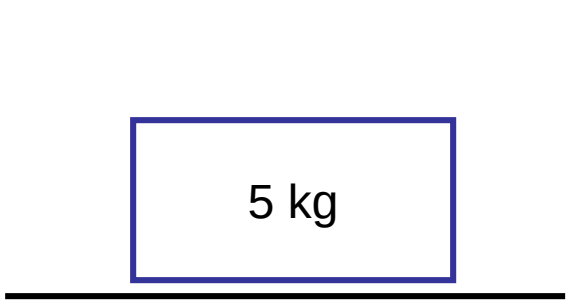
(limiting friction/normal reaction)

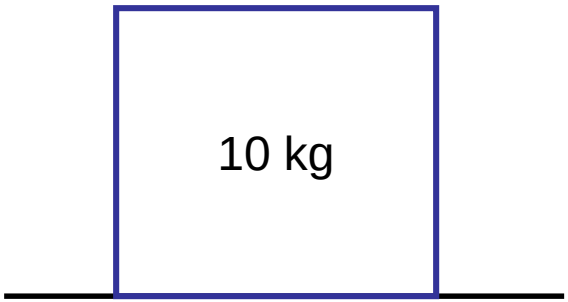
The coefficients of friction depend on both materials involved.

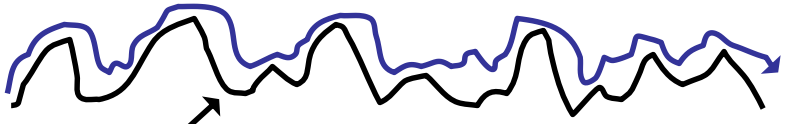
TABLE 4.1 Approximate Values for Coefficients of Static and Kinetic Friction between Certain Surfaces

Friction between Materials	μ_s	μ_k
Aluminum on aluminum	1.90	1.40
Glass on glass	0.94	0.35
Rubber on concrete		
dry	1.20	0.85
wet	0.80	0.60
Steel on aluminum	0.61	0.47
Steel on steel		
dry	0.75	0.48
lubricated	0.12	0.07
Teflon on steel	0.04	0.04
Teflon on Teflon	0.04	0.04
Waxed wood on snow	0.05	0.03
Wood on wood	0.58	0.40
Lubricated ball bearings	<0.01	<0.01
Synovial joints (at the ends of most long bones—for example, elbows and hips)	0.01	0.01

↑ Weight means ↑ Normal Force, and therefore, ↑ Maximum Friction







Surfaces are more compressed together and there are more interactions between molecules

LIMITING FRICTION FORCE

- The maximum value of the friction force at which the body resting on the another body start to slide.

If Limiting friction force is “F” and applied force is “P”, then

(i) If $F > P$ (no motion between two bodies)

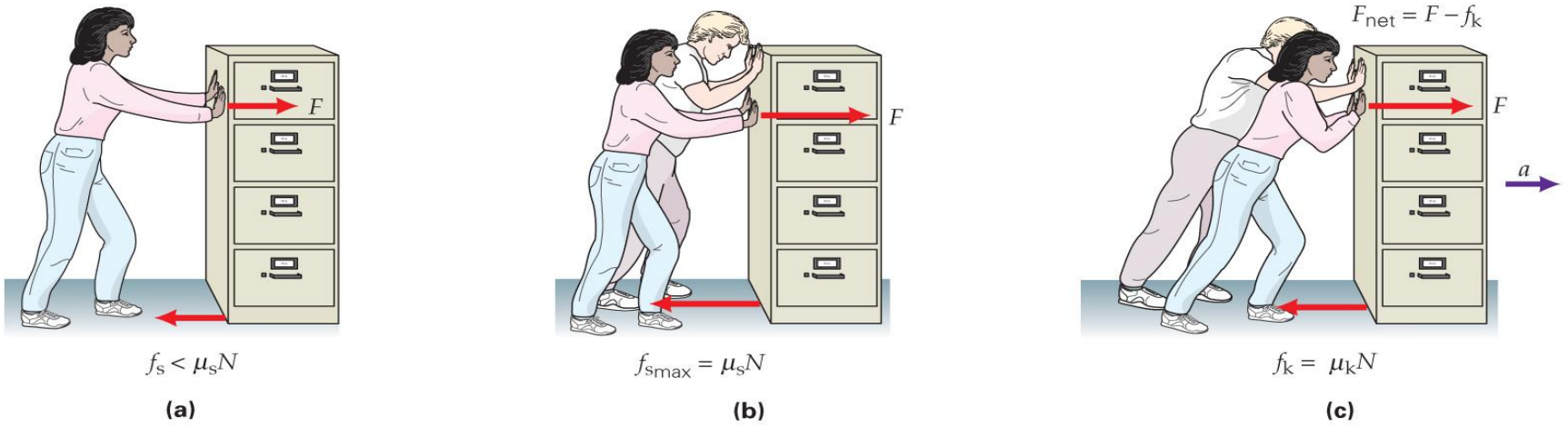
(ii) If $F = P$ (no motion between bodies)

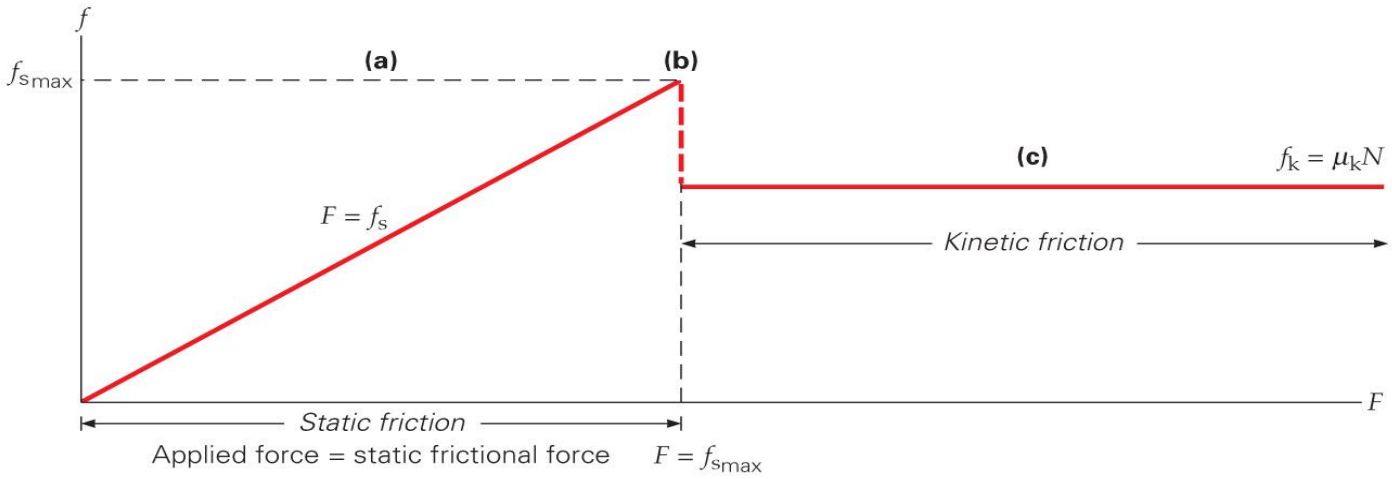
(iii) If $F < P$ (motion will be there)

Calculating Friction

- $F_{f\_max} = \mu F_N$
- F_{f_max} is the maximum force of friction
- μ (Mu) is the coefficient of friction
- F_N is the normal force
- Friction can range in value from $-F_{f\_max}$ to $+F_{f\_max}$
- μ depends on the types of surfaces that are interacting. It would be low for rubber on ice, but high for rubber on asphalt. It also depends on whether the surfaces are moving relative to each other (μ_{static} or $\mu_{dynamic}$)

what happens as the applied force increases: first, the static frictional force increases; then the kinetic frictional force takes over as the object begins to move.

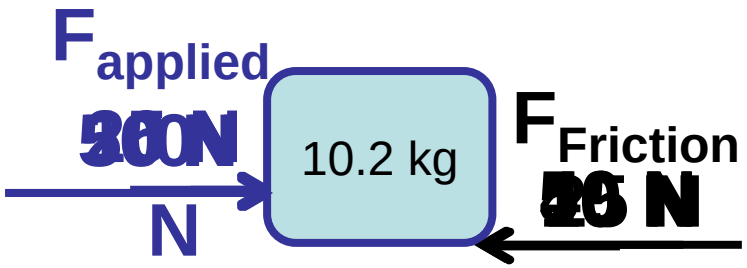


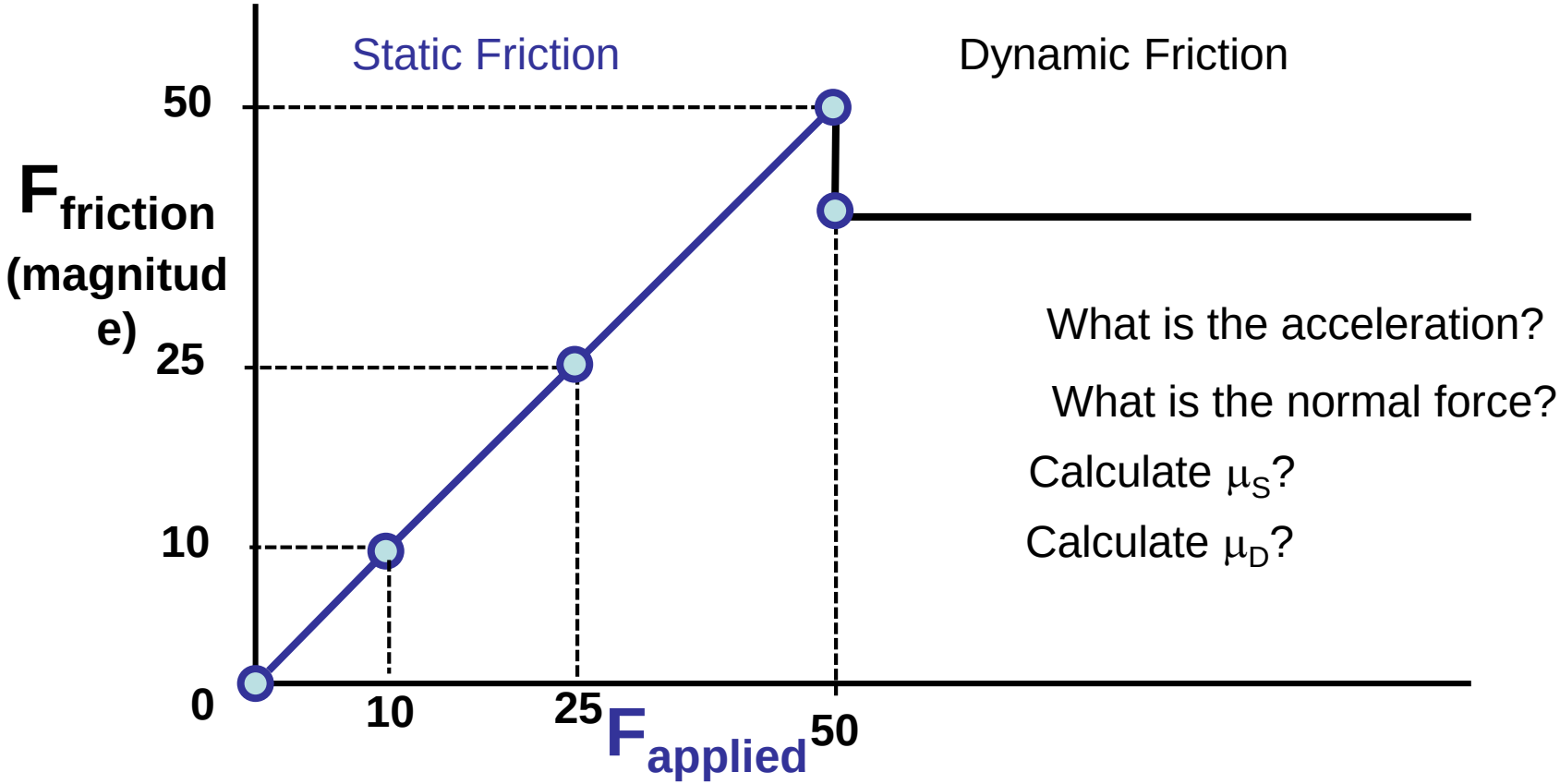


Friction is not always = F_{F_max}

Assume:

$F_{F\_max} = 50$ N



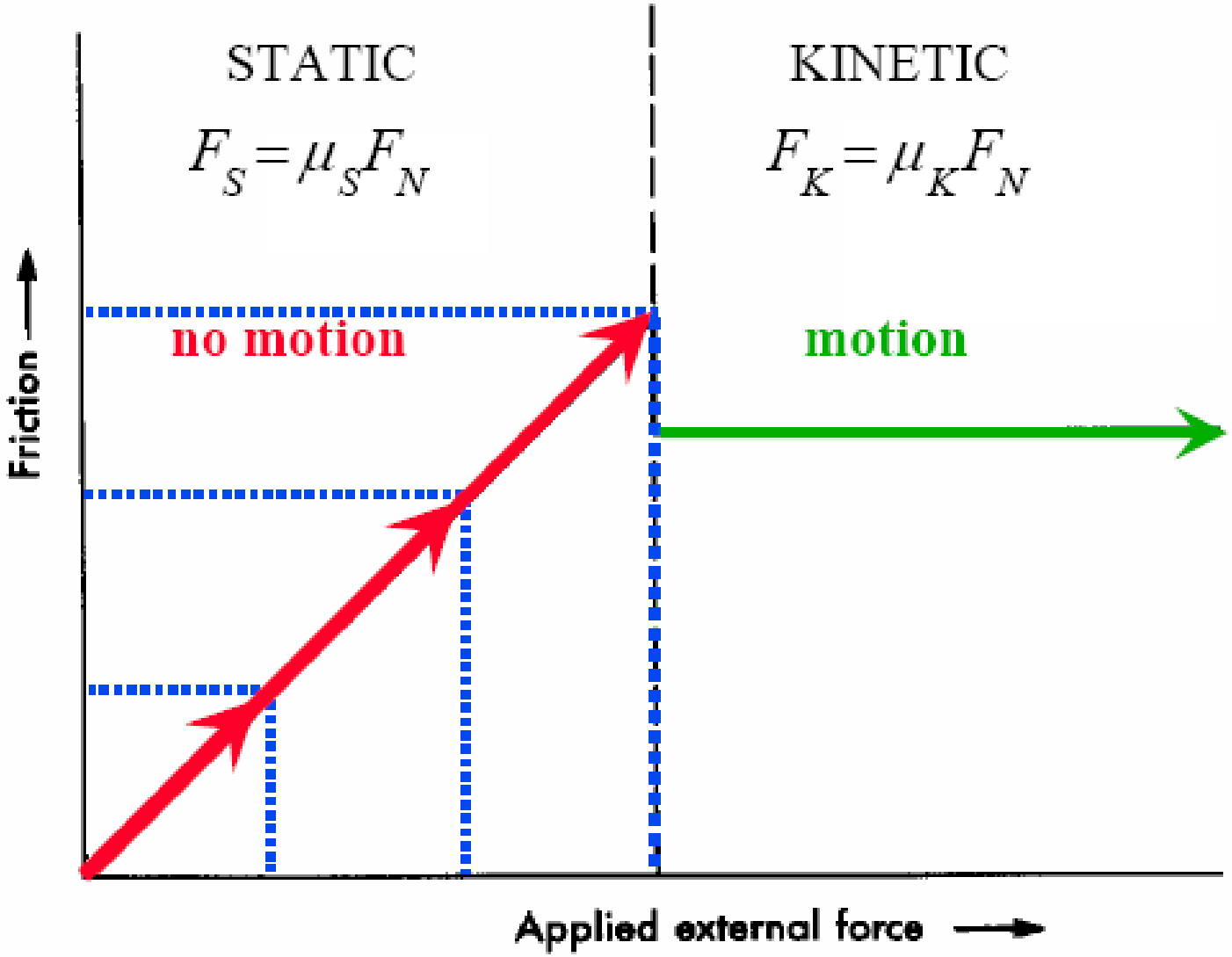


What is the acceleration?

What is the normal force?

Calculate μ_S?

Calculate μ_D?


STATIC
$F_S = \mu_S F_N$
KINETIC
$F_K = \mu_K F_N$
no motion
motion
Friction
Applied external force

Friction

The frictional force is proportional to the normal force. For static friction:

$$f_s \leq \mu_s N$$

The constant μ_s is called the coefficient of static friction.

The static frictional force may not have its maximum value; its value is such that the object does not move, and depends on the physical circumstances.

$$f_{s_{max}} = \mu_s N$$

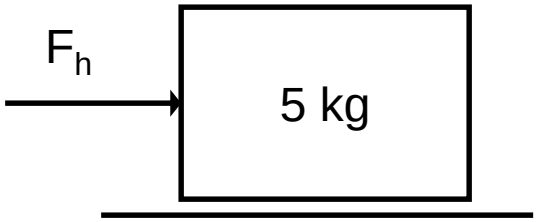
For kinetic friction:

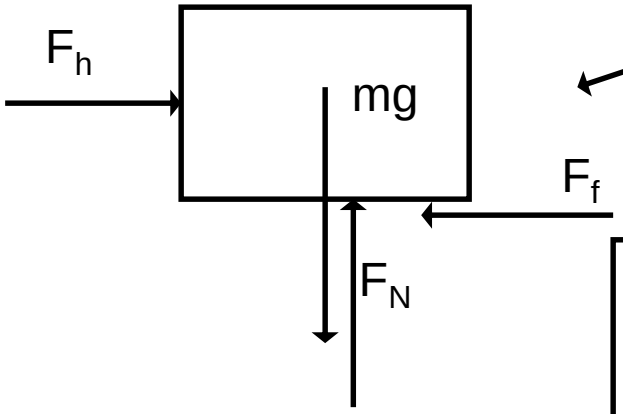
$$f_k = \mu_k N$$

The constant μ_k is called the coefficient of kinetic friction, and is usually smaller than μ_s.

Friction Example

A 5 kg block of wood rests on a ceramic counter. If the coefficient of static friction between the block and the counter is 0.4, what horizontal force is necessary to move the block.





Free body diagram

$\sum F_y = ma_y$
$F_N - mg = ma_y = 0$
$F_N = mg$

Normal force = $F_N = mg = 5 \times 9.81 = 49$ N

F_h= Friction force = $\mu F_N = 0.4 \times 49 =$ **19.6 N**

$\sum F_x = ma_x$
$F_h - F_f = ma_x = 0$
$F_h = F_f$

STATIC FRICTION

- "When friction occurs between two bodies which are not in motion then the friction is known as STATIC FRICTION“, and it is represented by "μs".
- It is given by

  $F_{max} = \mu s * Fn$

DYNAMIC FRICTION

" When the friction occurs between two bodies which have relative motion to each other, then the friction is known as the DYNAMIC FRICTION", and it is represented by "μ"or "μd".

F {max} = μ * Fn.

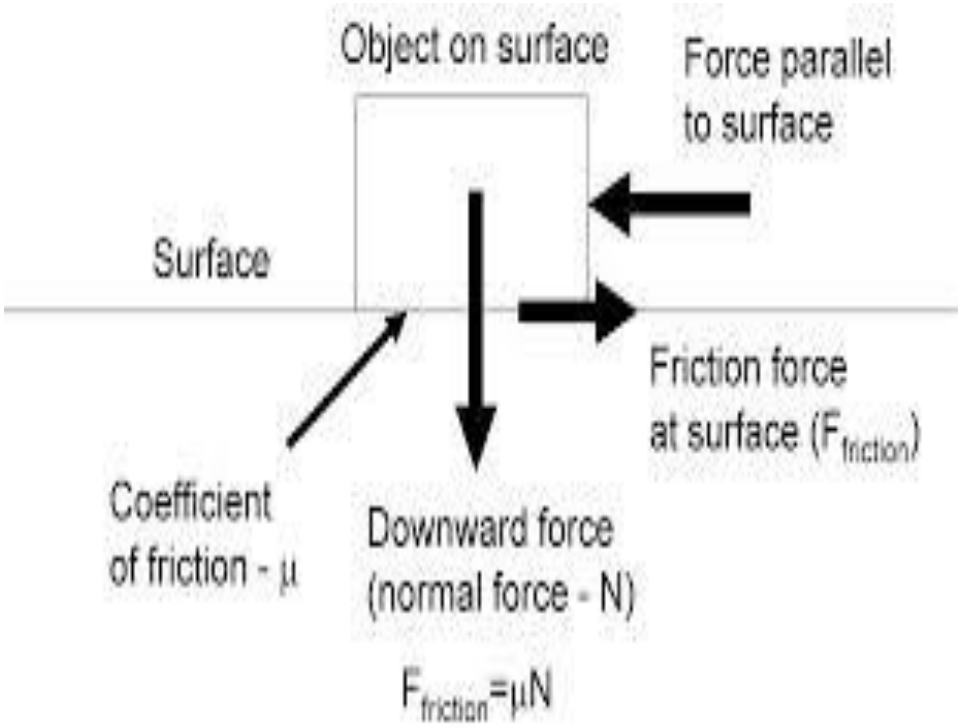
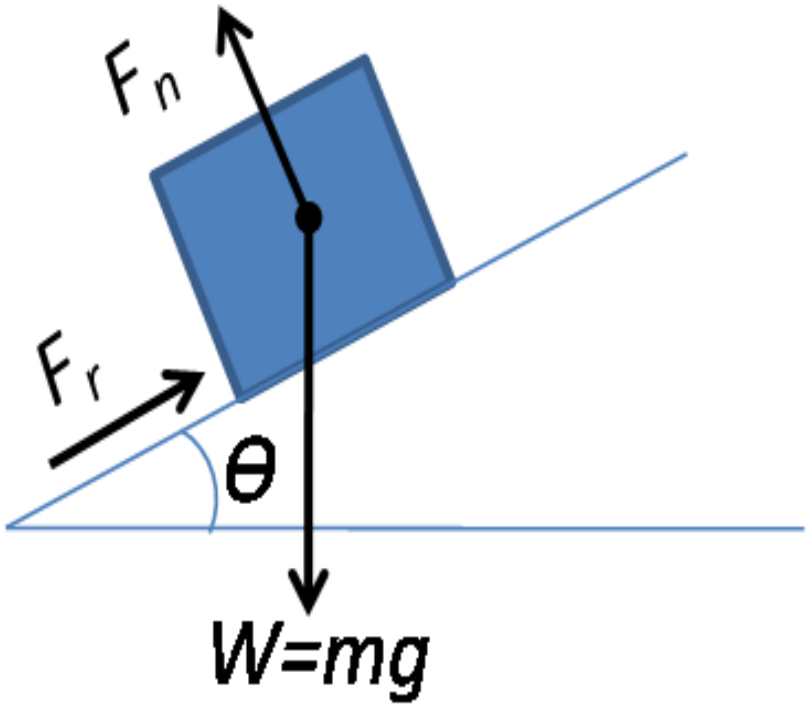


Figure 1 – Basic Definitions of the Coefficient of Friction

ANGLE OF REPOSE

"The minimum inclination of any plane to the horizontal is such that the body resting on the inclined plane tend to move down the plane, then this minimum inclination of the plane is known as ***ANGLE OF REPOSE".***



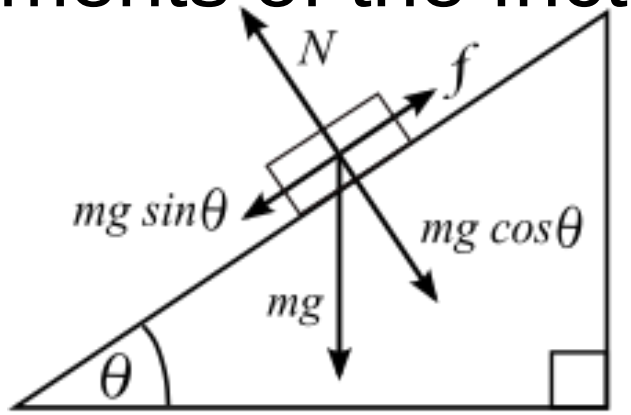
Angle of friction

- For the maximum angle of static friction between granular materials

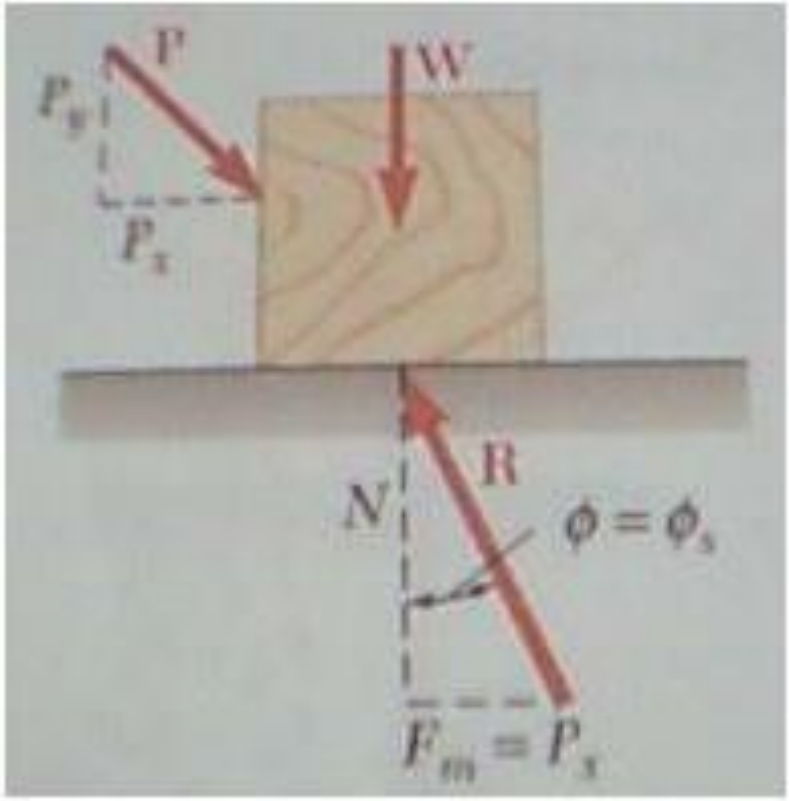
- For certain applications it is more useful to define static friction in terms of the maximum angle before which one of the items will begin sliding. This is called the angle of friction or friction angle. It is defined as: $\tan\theta = \mu_s$

Angle of friction

- where θ is the angle from horizontal and μ_s is the static coefficient of friction between the objects. This formula can also be used to calculate μ_s from empirical measurements of the friction angle.



ANGLES OF FRICTION



If the applied force P has a horizontal component Px which tends to move the block, the force R will have a horizontal component F and thus will form an angle Φ with the normal to the surface. This value is called the angle of static friction and is denoted Φs. Then from the geometry

$$\tan \Phi s = Fm / N$$

$$\tan \Phi s = \mu s$$

$$\tan \Phi k = \mu k$$

The major **difference** is that **angle of friction** is defined for rigid bodies while **angle of repose** is defined for granular particles like sand (**Angle of repose**). Again, **angle of repose** is a real **angle** and can be measured directly while **angle of friction** cannot.

Force of Friction

- The Force of Friction is directly related to the Force Normal.
  - Mostly due to the fact that BOTH are surface forces

$$F_f \propto F_N$$

$$\mu = \text{constant of proportionality}$$

$$\mu = \text{coefficient of friction}$$

$$F_{sf} = \mu_s F_N$$

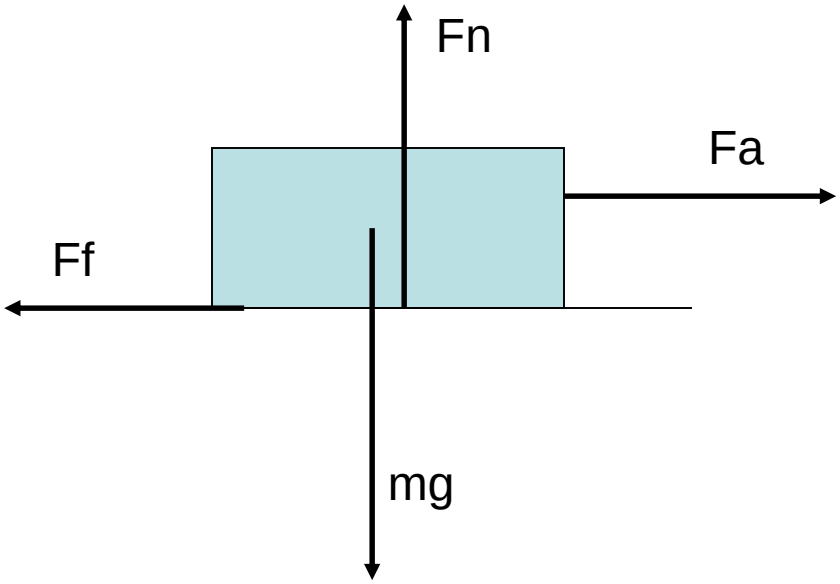
$$F_{kf} = \mu_k F_N$$

The coefficient of friction is a unitless constant that is specific to the material type and usually less than one.

Note: Friction ONLY depends on the MATERIALS sliding against each other, NOT on surface area.

Example

If the coefficient of kinetic friction between a 35-kg crate and the floor is 0.30, what horizontal force is required to move the crate to the right at a constant speed across the floor?



$$F_a = F_f \qquad F_f = \mu_k F_N$$

$$F_a = \mu_k F_N$$

$$F_N = mg$$

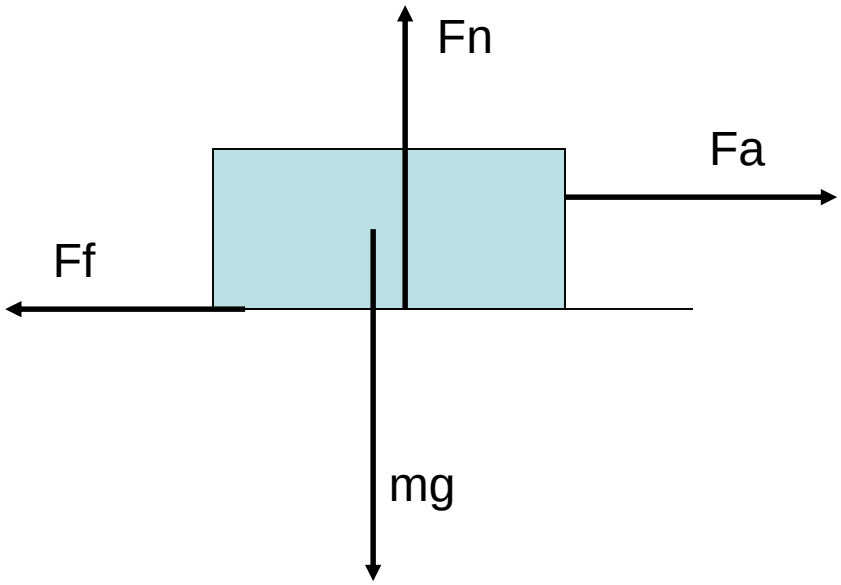
$$F_a = \mu_k mg$$

$$F_a = (0.30)(35)(9.8)$$

$$F_a = \quad \textbf{102.9 N}$$

Example

Suppose the same 35 kg crate was not moving at a constant speed, but rather accelerating at 0.70 m/s/s. Calculate the applied force. The coefficient of kinetic friction is still 0.30.



$$F_{NET} = ma$$

$$F_a - F_f = ma$$

$$F_a - \mu_k F_N = ma$$

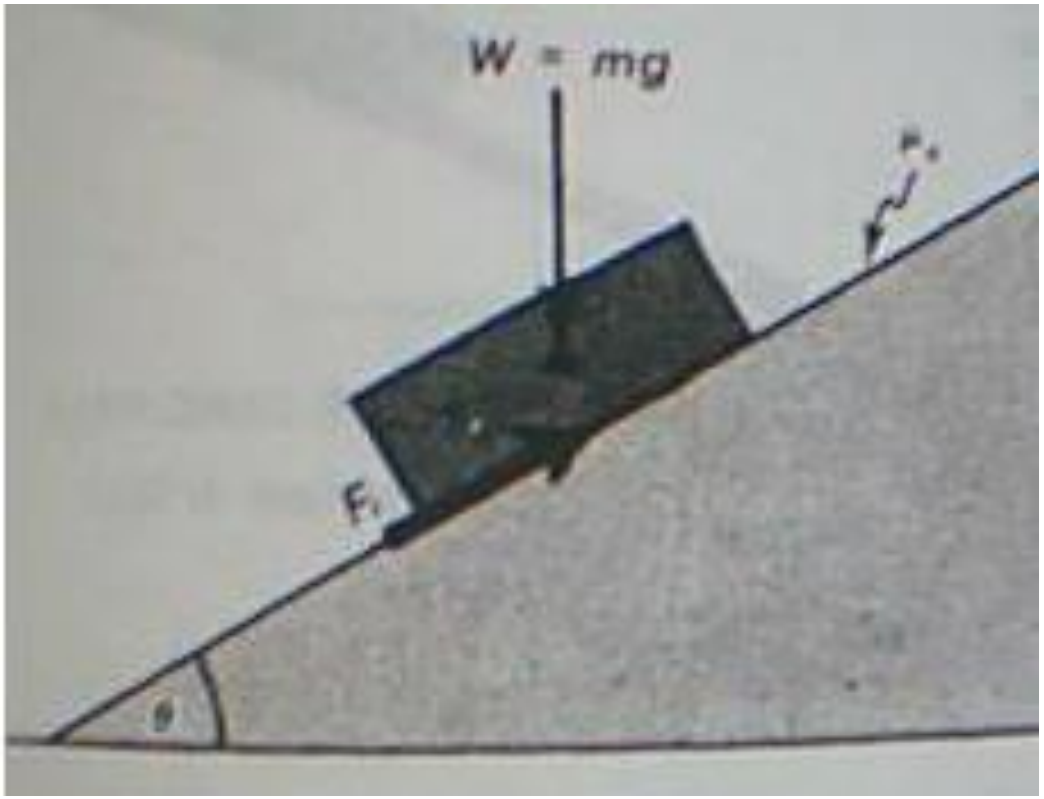
$$F_a - \mu_k mg = ma$$

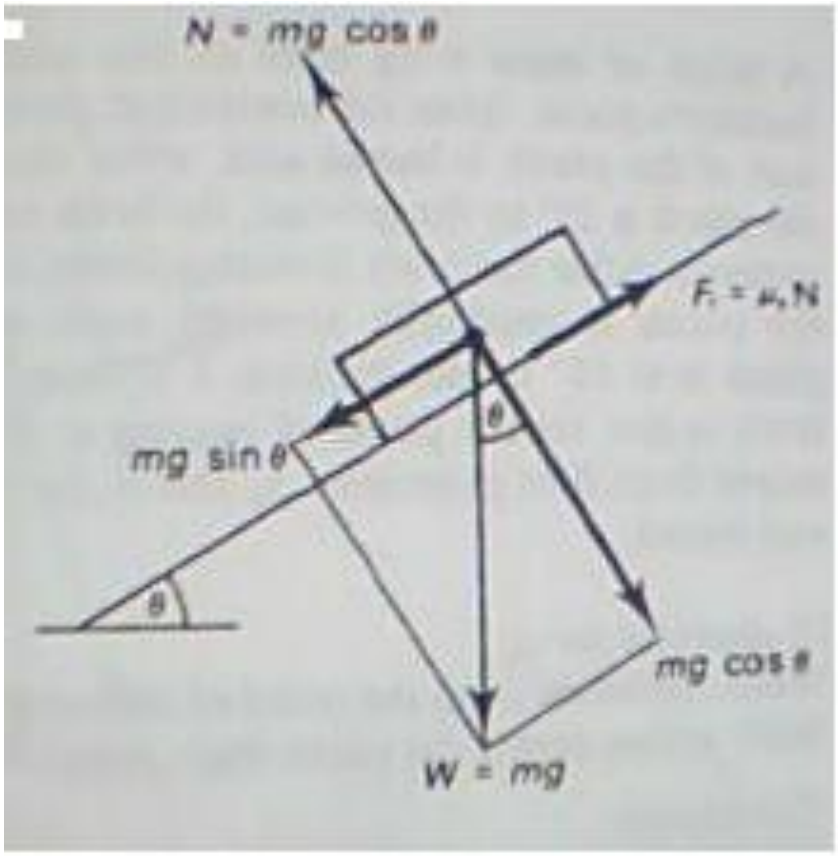
$$F_a = ma + \mu_k mg$$

$$F_a = (35)(0.70) + (0.30)(35)(9.8)$$

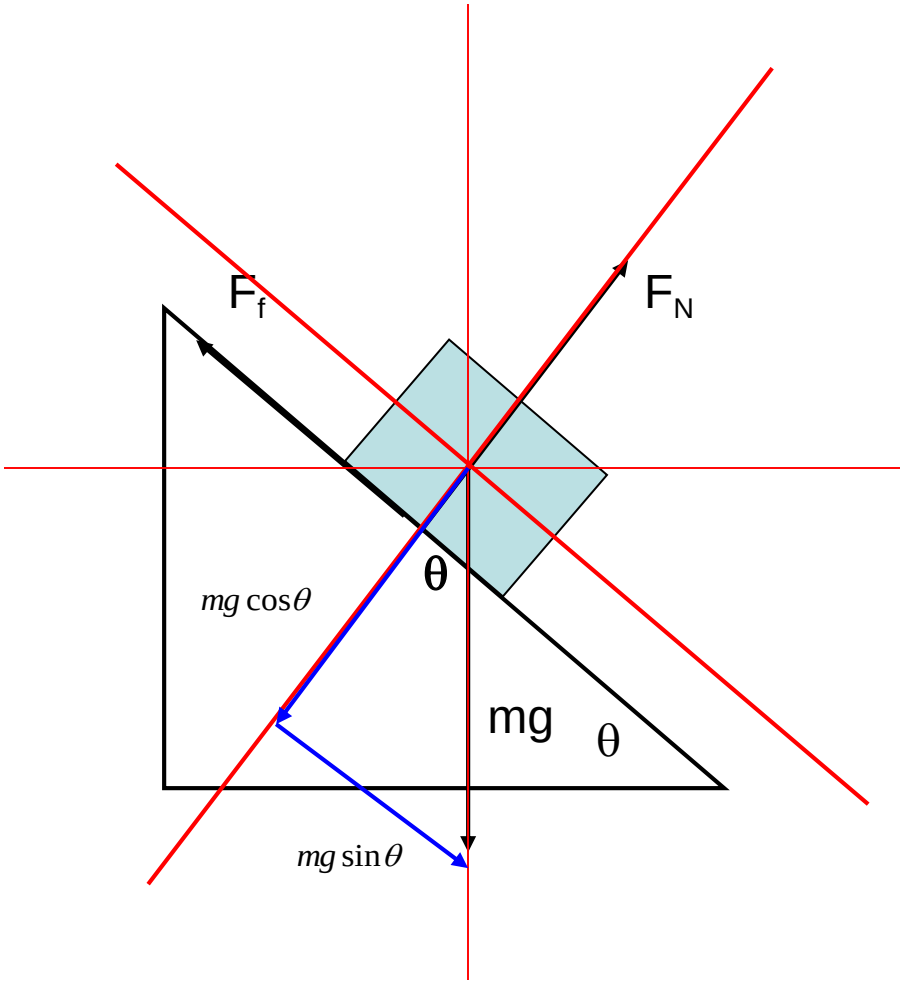
$$F_a = \textbf{127.4 N}$$

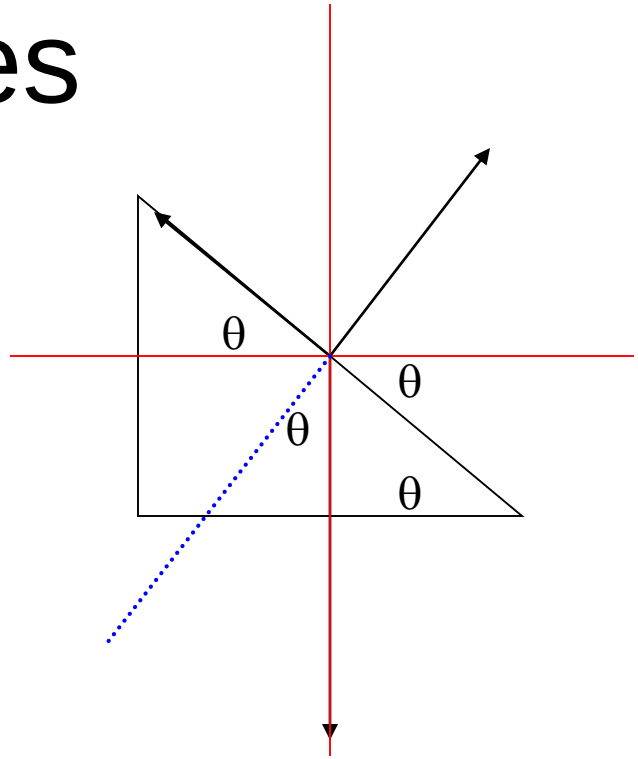
FRICTIONAL FORCES ON A INCLNED PLANE





Inclines

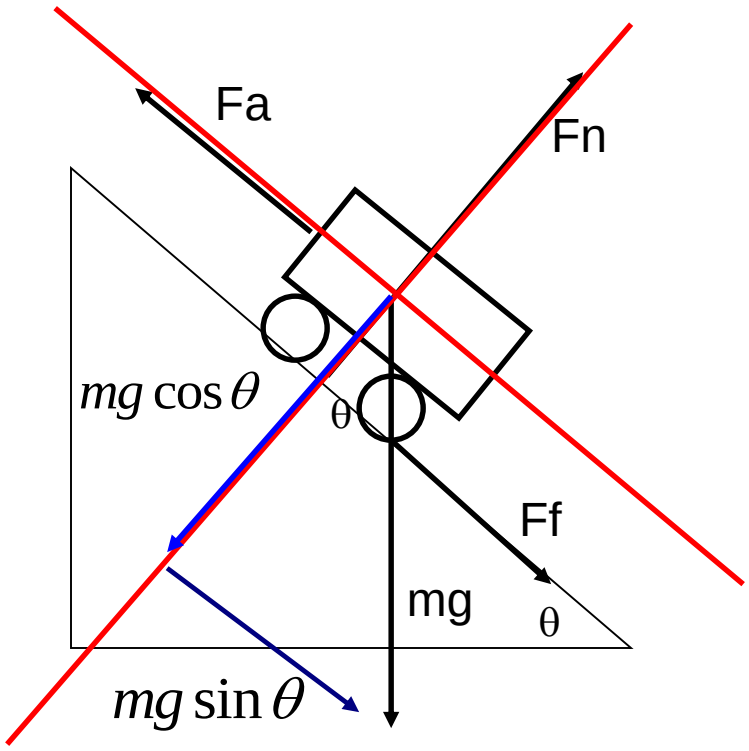




Tips
- Rotate Axis
- Break weight into components
- Write equations of motion or equilibrium
- Solve

Friction & Inclines

A person pushes a 30-kg shopping cart up a 10 degree incline with a force of 85 N. Calculate the coefficient of friction if the cart is pushed at a ***constant speed.***



$$F_a = F_f + mg\sin\theta \quad F_f = \mu_k F_N$$

$$F_a = \mu_k F_N + mg\sin\theta \quad F_N = mg\cos\theta$$

$$F_a = \mu_k mg\cos\theta + mg\sin\theta$$

$$F_a - mg\sin\theta = \mu_k mg\cos\theta$$

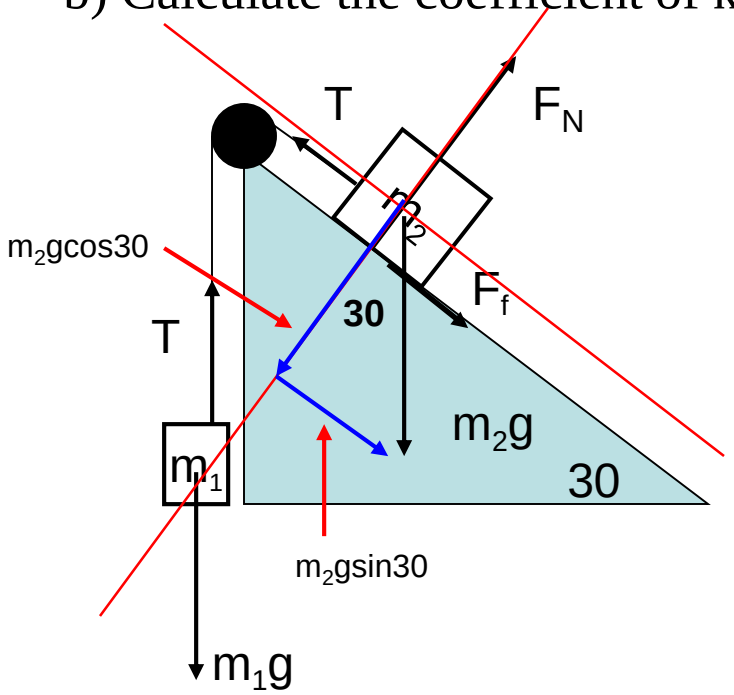
$$\mu_k = \frac{F_a - mg\sin\theta}{mg\cos\theta}$$

$$\mu_k = \frac{85 - (30)(9.8)(\sin 10)}{(30)(9.8)(\cos 10)} = \mathbf{0.117}$$

Example 2

A 5-kg block sits on a 30 degree incline. It is attached to string that is thread over a pulley mounted at the top of the incline. A 7.5-kg block hangs from the string.

- a) Calculate the tension in the string if the acceleration of the system is 1.2 m/s/s
- b) Calculate the coefficient of kinetic friction.



$$F_{NET} = ma$$

$$m_1 g - T = m_1 a$$

$$T - (F_f + m_2 g \sin\theta) = m_2 a$$

$$F_N = m_2 g \cos\theta$$

Answer

$$F_{NET} = ma$$

$$m_1 g - T = m_1 a$$

$$m_1 g - m_1 a = T$$

$$(7.5)(9.8) - (7.5)(1.2) = T$$

$$T = \textbf{64.5 N}$$

$$T - (F_f + m_2 g \sin\theta) = m_2 a$$

$$T - F_f - m_2 g \sin\theta = m_2 a$$

$$T - \mu_k F_N - m_2 g \sin\theta = m_2 a$$

$$T - m_2 a - m_2 g \sin\theta = \mu_k F_N$$

$$\frac{T - m_2 a - m_2 g \sin\theta}{F_N} = \mu_k \qquad F_N = m_2 g \cos\theta$$

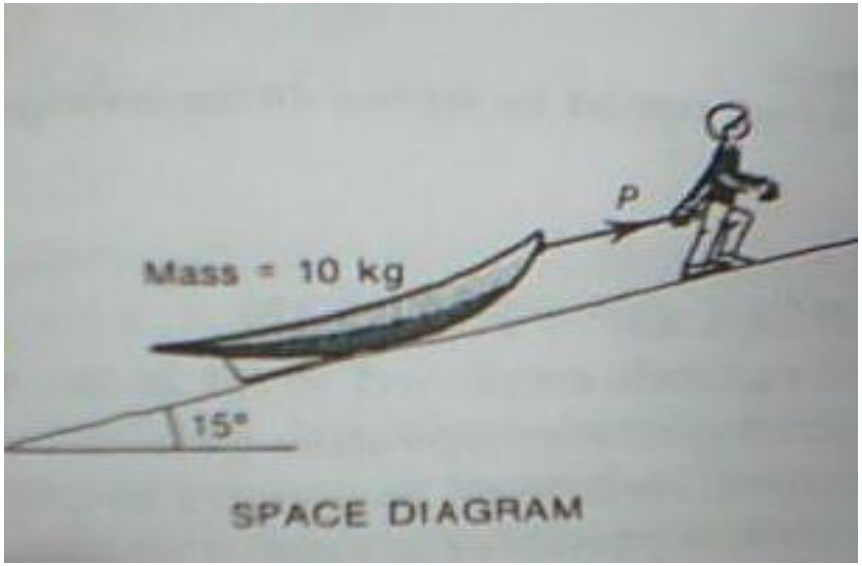
$$\frac{T - m_2 a - m_2 g \sin\theta}{m_2 g \cos\theta} = \mu_k$$

$$\frac{64.5 - (5)(1.2) - (5)(9.8)(\sin 30)}{(5)(9.8)(\cos 30)} = \mu_k$$

$$\mu_k = \textbf{0.80}$$

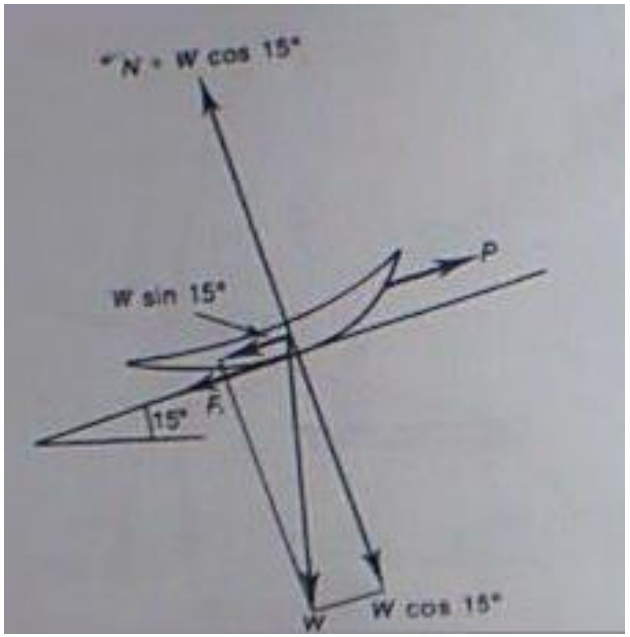
Example 3

- A sand sled of mass 10kg is used on a sand dune having a slope of 15°. If the coefficient of friction is 0.35, what force must the boy exert on the tow rope to drag the sand sled up the dune?



ANSWER

FBD



P – W sin 15° - Fr = 0

Since Fr = μ N

= 0.35 mg cos 15°

= 0.35 (10) (9.8) cos 15°

= 33.1N

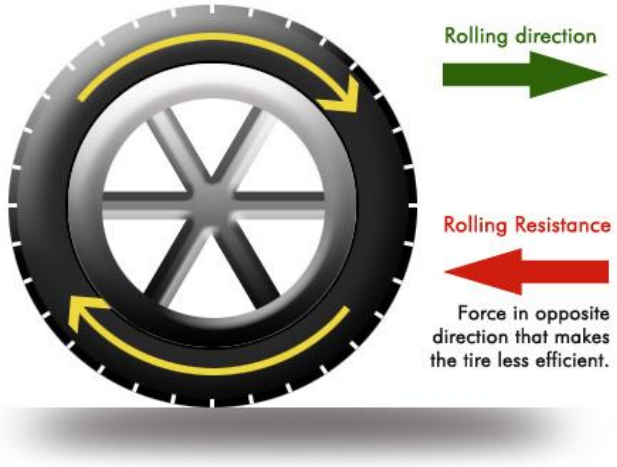
P – (10) (9.8) sin15° - 33.1 = 0

P = 58.5N

APPLICTIONS OF FRICTION

Rolling resistance

- Rolling resistance is the force that resists the rolling of a wheel or other circular object along a surface caused by deformations in the object and/or surface.
- Generally the force of rolling resistance is less than that associated with kinetic friction.
- Typical values for the coefficient of rolling resistance are 0.001.
- One of the most common examples of rolling resistance is the movement of motor vehicle tires on a road, a process which generates heat and sound as by-products.



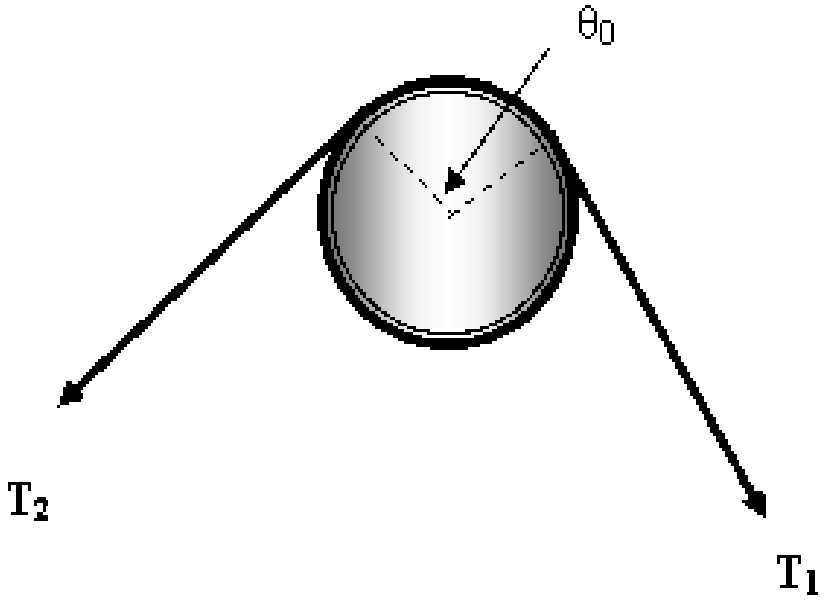
Belt friction

- Belt friction is a physical property observed from the forces acting on a belt wrapped around a pulley, when one end is being pulled.

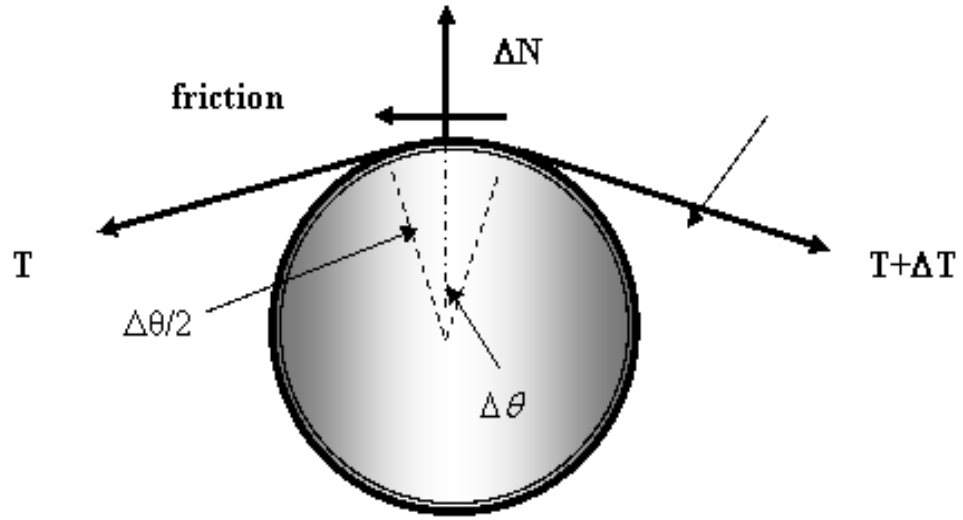
- The resulting tension, which acts on both ends of the belt, can be modeled by the belt friction equation.

- In practice, the theoretical tension acting on the belt or rope calculated by the belt friction equation can be compared to the maximum tension the belt can support.

$$T_1 = T_2 e^{\mu_s \theta_0}$$



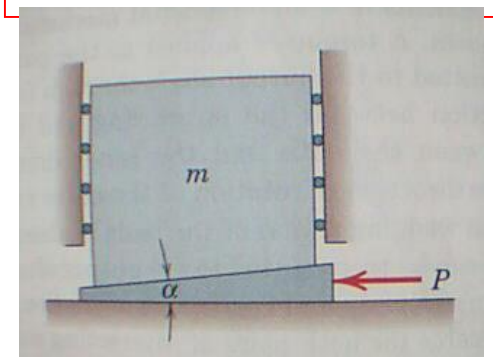
A rope going over a pulley



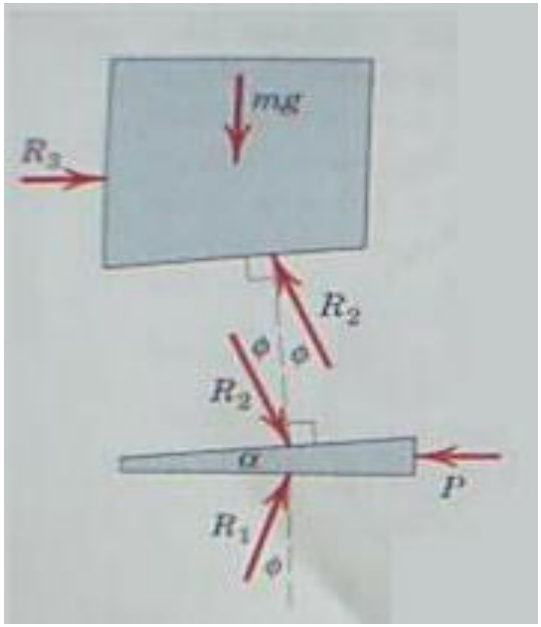
Forces over a small section of the rope

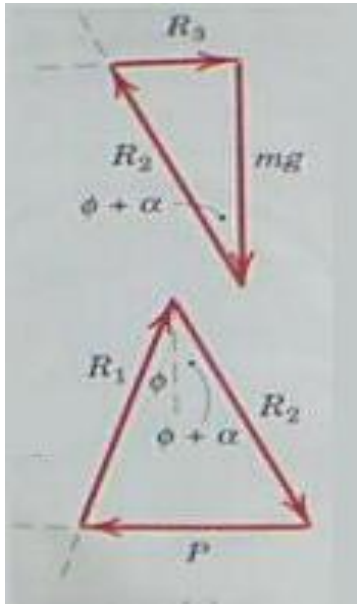
The Wedge

- A wedge is one of the simplest and most useful machine. A wedge is used to produce small adjustments in the position of the body or to apply large forces. Wedges largely depend on friction to function.



A wedge used to position or lift a large mass m



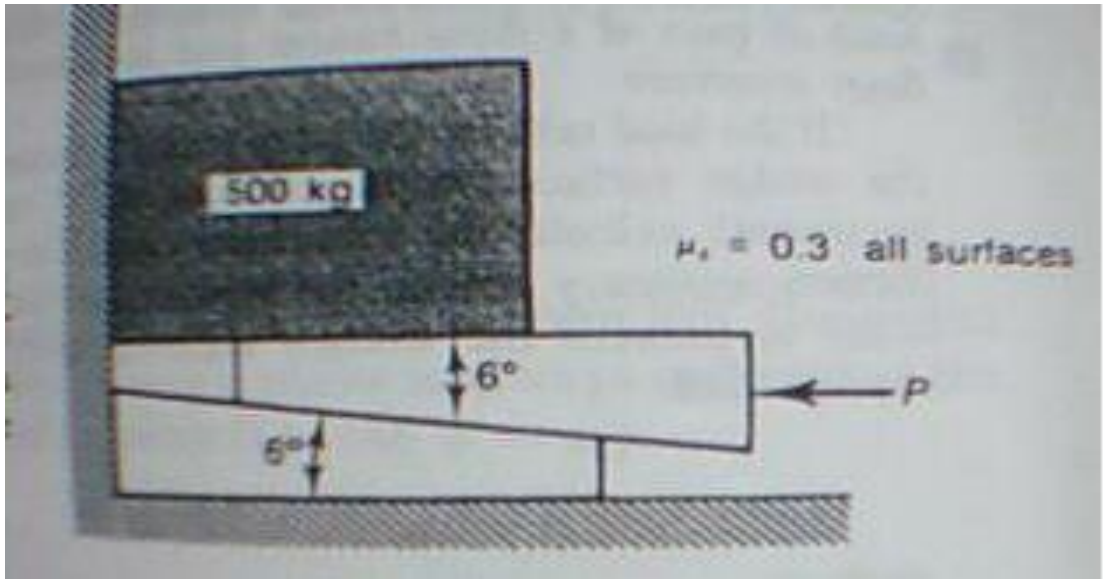


The FBD showing the force triangle for the mass and the wedge.

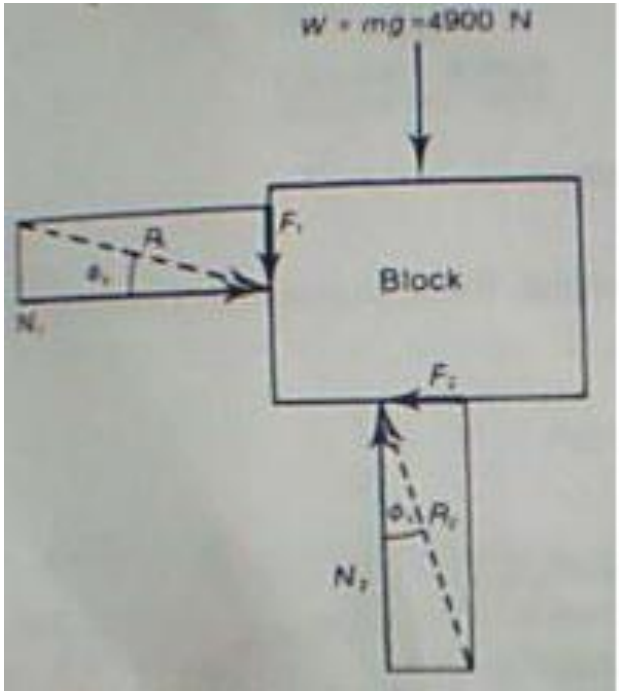
Simple application example

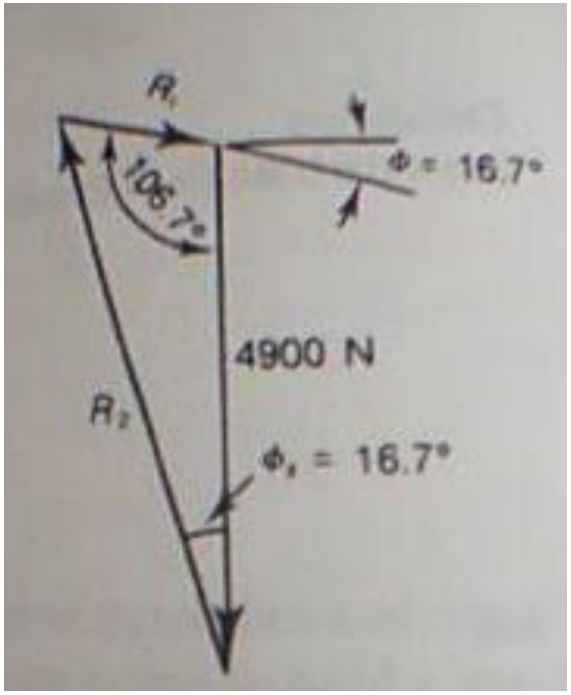
Example

- A heavy block of mass 500kg is to be lifted vertically by the system of two wedges as shown. If the coefficient of the static friction for the all the surfaces is 0.3, determine the force P which will cause the system to be on the point of movement.



Answer





For the block:

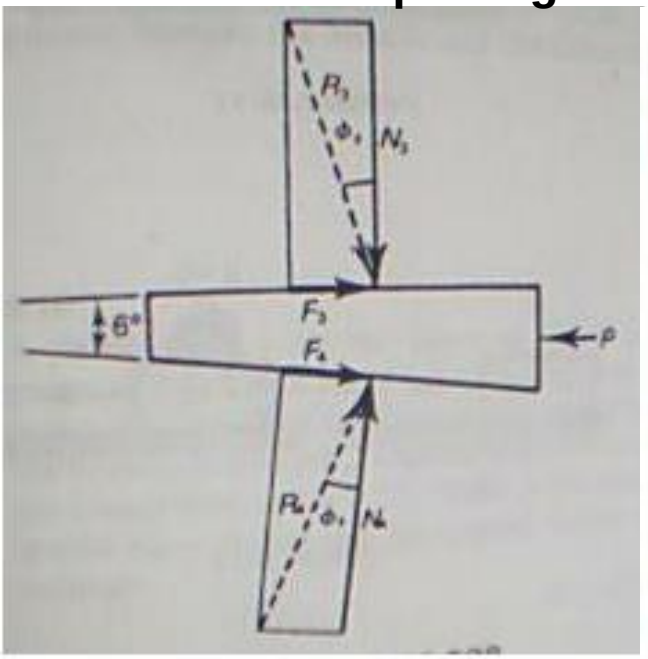
$$\frac{4900}{\sin 56.6^\circ} = \frac{R2}{\sin 106.7^\circ}$$

R2 = 5667N

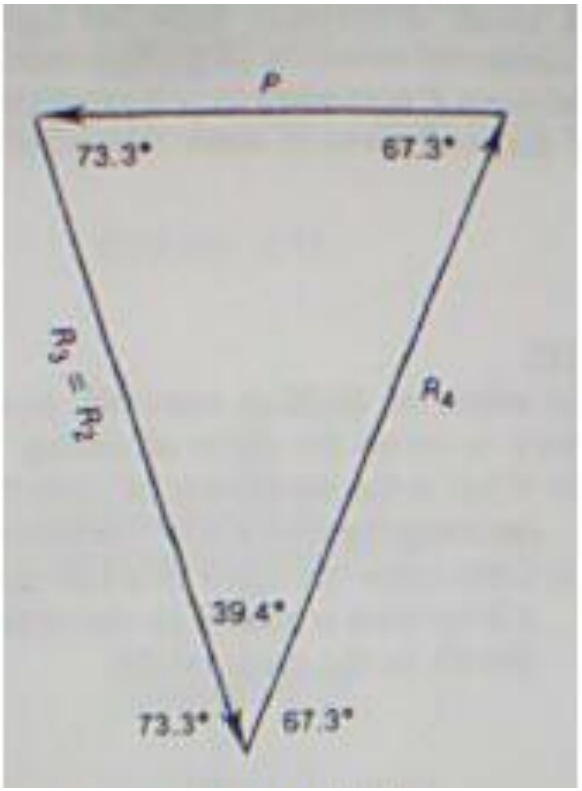
Forces on the block **Triangle of forces for the block**

Answer

Forces on the top wedge.



Force triangle for the wedge



$$\frac{P}{\text{Sin } 39.4^\circ} = \frac{5667}{\sin 67.3^\circ}$$

P = 3899N

Take Home Message

Friction is the resistance to motion that occurs when different surfaces are in contact.

Static friction:

$$f_s \leq \mu_s N$$

$$f_{s_{max}} = \mu_s N$$

Kinetic friction:

$$f_k = \mu_k N$$

Any Question??

End of Part I (Statics)