1. Details of Module and its structure

Module Detail	
Subject Name	Physics
Course Name	Physics 01 (Physics Part-1, Class XI)
Module Name/Title	Unit 3, Module 5, Friction Chapter 5, Laws of motion
Module Id	Keph_10505_eContent
Pre-requisites	Basic understanding of concept of force, weight, Normal reaction, drawing of free body diagrams, vector addition and resolution of vectors
Objectives	After going through this lesson, the learners will be able to: • Describe friction as a contact force that opposes motion and generates heat, sound and electricity. • Distinguish between static, kinetic and rolling friction • Explain the cause of friction • Understand the self-adjusting nature of static friction • State and apply laws of friction • Define coefficient of friction • State the factors on which the friction depends • Describe ways of increasing/reducing friction • Describe common occurrences of friction in everyday life • Relate to latest scientific research & technological advances associated with friction
Keywords	Friction, kinetic friction, static friction, maximum static friction, coefficient of friction, rolling friction

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TABLE OF CONTENTS

1. UNIT SYLLABUS

Chapter 5: Laws of Motion

Intuitive concept of force, Inertia, Newton's first law of motion, momentum and Newton's second law of motion, Impulse; Newton's third law of motion.

Law of conservation of linear momentum and its applications.

Equilibrium of concurrent forces, Static and kinetic friction, laws of friction, rolling friction, lubrication.

Dynamics of uniform circular motion: Centripetal force, examples of circular motion (vehicle on a level circular road, vehicle on banked road).

2. MODULE-WISE DISTRIBUTION OF UNIT SYLLABUS 7 Modules

The above unit is divided into seven modules as follows:

Module 1	• Force • inertia • First law of motion
Module 2	• Momentum • Second law • Impulse • F=ma • Constant and variable force
Module 3	• Third law • Conservation of linear momentum and its applications
Module 4	• Types of forces (tension, normal, weight, …) • Equilibrium of concurrent forces • FBD
Module 5	• Friction • Coefficient of friction • Static friction • Kinetic friction • Rolling friction • Role of friction in daily life
Module 6	• Dynamics of circular motion • Centripetal force • Banking of roads
Module 7	• Using laws of motion to solve problems in daily life

MODULE 5

3. WORDS YOU MUST KNOW

- Rest: A body is said to be at rest if it does not change its position with time with respect to its surroundings.
- Motion: A body is said to be in motion if it changes its position with time with respect to its surroundings.
- Velocity: The time rate of change of displacement is called velocity.
- Uniform motion: When a particle has equal displacements, in equal intervals of time, (howsoever small this time interval may be) it is said to have a uniform motion. The acceleration for a particle in uniform motion would be zero.
- Momentum (**p**): An indicator of the impact capacity of a moving body. We have **p**= m**v**
- Acceleration: Time rate of change of velocity of a particle, equals its acceleration.
- Vector: A physical quantity that needs both a magnitude and a direction for its specification.
- Vector Algebra: The branch of mathematics that deals with computations involving addition, subtraction, and multiplication of vectors.
- Force: A body will continue in its state of rest, or uniform motion until and unless it is acted upon by an external unbalanced force.
- Inertia: An inherent property of all objects; an object continues in its state of rest or uniform motion unless and until a non-zero external force acts on it.
- Impulse: Rate of change of momentum.
- Equations of motion: a set of equations relating initial velocity (u) final velocity (v) time elapsed for the change in velocity(t), distance travelled (s) and acceleration (a)
- Laws of motion: Rules /Laws that give the cause of state of motion and state of rest of a body
- Free body diagram: a diagram which shows all the concurrent forces acting on a body, such that the net force can be calculated to describe the state of rest or motion of that body

4. INTRODUCTION

The word ‘friction’ comes from Latin word ‘fricare’ which means ‘to rub’. Friction appears anywhere, whenever two things rub against each other – practically everywhere around us.

Friction is unavoidable. Huge amounts of money, time and energy are spent in countering friction otherwise it would stop every moving object; yet without friction, we could not walk and our cars would not go anywhere. It heats up machines and makes them noisy but without friction they would not even hold together. Friction poses challenges yet we cannot do without it.

Friction can exist between dry solid surfaces and it is called dry friction.

When it operates between a solid and a fluid or between two fluids, it is called fluid friction.

In this module, we will learn about solid or dry friction.

5. FRICTIONAL PHENOMENA BETWEEN SURFACES

When surfaces rub, friction acts. When two stationary surfaces simply lie touching each other, there is no tendency to rub, hence friction between them is not defined.

Surfaces rub or tend to rub only when we push one over another. Hence friction acts only when there is a force applied with intention of sliding one surface against the other.

When a force is applied and two surfaces slide over each other, the friction between them is called **kinetic Friction.**

When a force is applied but two surfaces do not slide over each other, the friction between surfaces is called **static friction.**

When a force is applied and one surface rolls over another, the friction operating between surfaces is called **rolling friction**.

Let us learn about these frictional phenomena in greater detail.

Figure 1 (see credits at the end)

No friction acts during 'Namaste' because there is no attempt to slide hands against each other.

kinetic friction acts when hands are rubbed together

Static friction acts when one hand is pressed against another and pushed forward but rubbing has not yet started.

Rolling friction acts When a rolling pin rolls over a chapati

6. KINETIC FRICTION

Need to consider kinetic friction as a force. Consider the following:

Send a block sliding across a table. It slows and then stops. This means the block has acceleration opposite to velocity. The velocity of the block is parallel to the surface of the table. Hence the acceleration on the block must act parallel to the table surface opposite to velocity. Therefore, as per Newton's second law, a force must act on the block parallel to the table surface opposite to velocity. This force can arise only due to contact with the table.

This force must be a contact force applied by the table on the block parallel to its surface. Push the block horizontally so as to slide it on the table with constant velocity.

Why does it move with constant velocity? Shouldn't your push accelerate it?

This means there must be another force counterbalancing your push on the block, directed parallel to the surface. This force must be a contact force applied by the table on the block. Hence we conclude:

Whenever two objects slide over each other, rubbing the surfaces in contact, a contact force opposes the slipping and acts parallel to the plane of contact. This contact force is force of kinetic friction.

Definition: Force of kinetic friction is the force that opposes slipping between two surfaces in contact.

Direction of Kinetic friction:

Force of kinetic friction acts tangentially to the surfaces in contact and always opposite to velocity because it always slows down the object. Usually, it does not make an object go faster like other forces. Kinetic friction on a body A sliding against body B is always opposite to the velocity of A with respect to B. Care should be taken while determining the direction of velocity. Here, velocity to be considered is always with respect to the body applying the force of friction.

Magnitude of kinetic friction

Magnitude of kinetic friction (f_k) is proportional to the normal force (N) acting between the objects.

$f_k = \mu_k N$ where μ_k is the proportionality constant.

This relation only gives the magnitude of f_k.

- f_k is not in the direction of N.
- This law is empirical and not derived from any fundamental theory of physics.
- Magnitude of kinetic friction is independent of area of contact so long as the normal force remains the same.
- Magnitude of kinetic friction is independent of the speed of the sliding so long as the relative speeds are not too large.
- The proportionality constant μ_k is called the coefficient of kinetic friction.
- The value of μ_k can lie between zero to infinity i.e. $0 < \mu_k < \infty$.
- Its value can only be determined experimentally by measuring frictional force f_k and normal force N and then by finding their ratio.
- μ_k has no units, being a ratio of two forces.

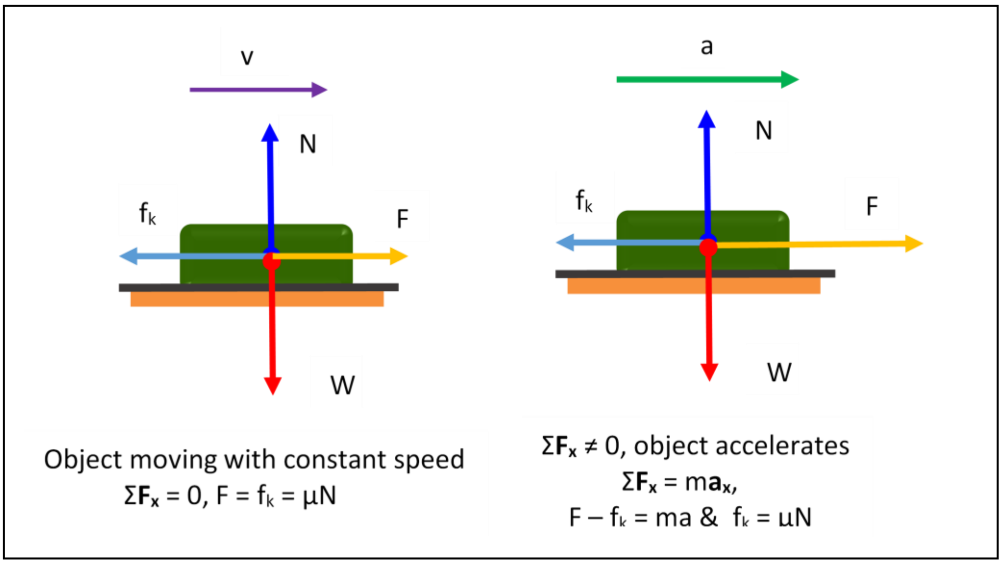
The value of μ_k depends on:

(a) The nature of materials.
(b) Nature of surfaces in contact.

μ_k is generally larger for rough surfaces as compared to smooth surfaces.

Surface conditions like oxidation of a metal surface, dirt, water or grease can dramatically change the coefficient of friction for the given materials

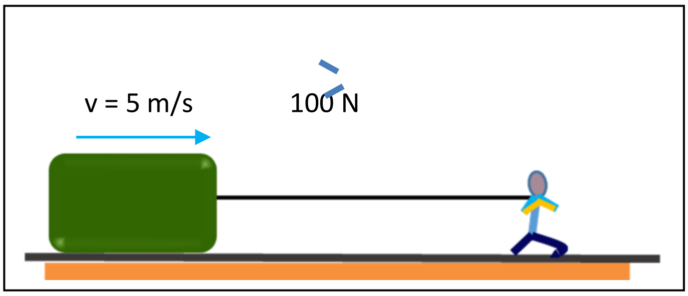
The value of μ_k does not depend on frictional force f_k and normal force N, nor on the speed of the bodies.



CHECK YOUR UNDERSTANDING:

EXAMPLE

A boy pulls a block with a force of 200 N to the right. The block moves with a constant speed of 5 m/s. What is the magnitude and direction of the force of kinetic friction on the block?



SOLUTION

100 N towards left. Because the speed is constant therefore the net force on the block must be zero. The force of kinetic friction must be equal to the pull.

EXAMPLE

In the question given above, if the mass of the block is 50 kg, what is the coefficient of kinetic friction between the block and the floor?

SOLUTION

Coefficient of kinetic friction between the block and the floor = 0.2

Hint: (using $f_k = \mu_k N$. Here N = W = mg = 500 N, f_k = 100 N)

EXAMPLE

In the question given above, if the rope breaks, how long does it take for the stone to come to rest?

SOLUTION

2.5 s

Hint:

Once the rope breaks, the force applied by the boy is gone.

The system is no longer in equilibrium.

The kinetic friction, the net force in the -ve x-direction, now equals ma.

Using $\Sigma F_x = ma_x$, $- f_k = ma$, $a = - f_k /m = - 2 \ m/s^2$

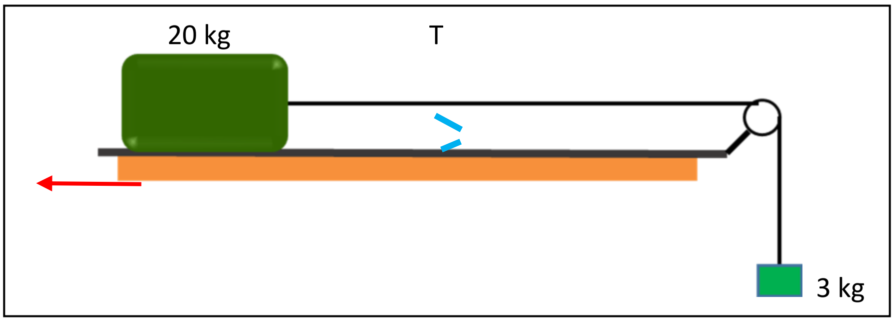
Using v = u + at and v = 0, u = 5 m/s, t = 2.5 s

EXAMPLE

What is the acceleration of the two block system (as shown in the figure below) if the coefficient of kinetic friction between the bigger block and the surface is 0.04?

What is the tension in the string?

(Take g=10 m/s^2 and the string to be negligible mass)



SOLUTION

$a = 0.96\ m/s^2$ and 27.1 N

Both the blocks have same acceleration since the string is inextensible and the pulley is smooth.

Applying Newton's second law to motion of 3 kg block: $30 – T = 3a$

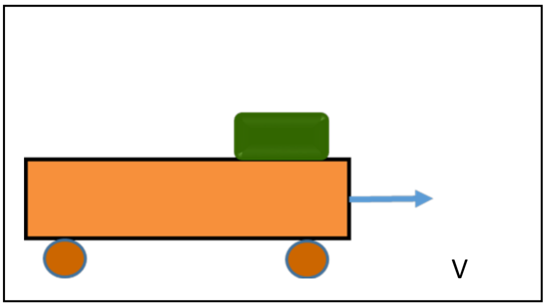
Applying Newton's second law to motion of 20 kg block: $T - f_k = 20a$

Also, $f_k = \mu_k N$

EXAMPLE

Figure below shows a trolley moving on a horizontal road with a constant speed V. A small block placed the trolley slips on the trolley and falls from the rear end.

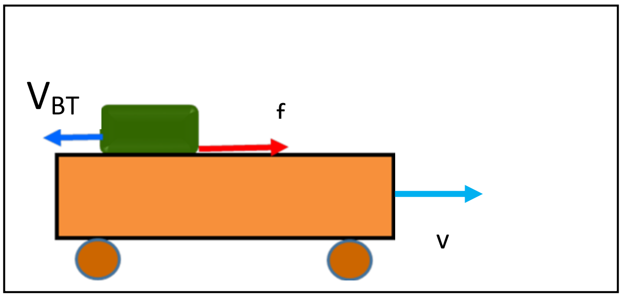
What is the direction of kinetic friction acting on the block?



SOLUTION

Towards right.

For finding the direction of kinetic friction, we observe the direction of velocity of the block with respect to the trolley (V_{BT}). The kinetic friction is opposite to V_{BT}.



7. STATIC FRICTION

Need to consider static friction as a force

Consider the following:

Push horizontally on a heavy block kept on a table. It does not move. This means there must be another force on the block to counteract your push. This force must act opposite to your push and must be equal in magnitude to exactly counter balance your push. This force can arise only due to contact with the table. This force must be a contact force applied by the table on the block parallel to its surface. This contact force is force of static friction. Now push harder. The block still does not move. This means the force of static friction can adjust its value so that it still balances your push. So, static friction is a self-adjusting force. Now push with your full strength. The block begins to slide. This means force of static friction has a maximum magnitude. When your push exceeds that maximum, the block begins to slide.

HENCE WE CONCLUDE:

Whenever one object is pushed over another without producing any slipping, a contact force opposes the applied force to prevent slipping. It acts parallel to the plane of contact. This contact force is force of static friction. It is a self-adjusting force and has a maximum value.

DEFINITION: Force of static friction is the force that prevents slipping between two stationary surfaces in contact.

DIRECTION OF STATIC FRICTION: Force of static friction acts tangentially to the surface, always opposite to the lateral force that tries to move the body. It acts in the direction needed to prevent slipping.

If in doubt, imagine surfaces to be frictionless and consider the direction of slipping in absence of friction. The static friction force on body A by body B will be opposite to the direction of slipping of body A respect to body B.

MAGNITUDE OF STATIC FRICTION:

Magnitude of static friction can lie between zero to f_{max} i.e. $0<f_s \leq f_{max}$.

Magnitude of static friction is zero when there is no other force parallel to surfaces in contact. It starts increasing with increase in applied force. Magnitude of static friction is maximum (f_{max}) just before motion starts. Maximum force of static friction (f_{max}) is proportional to the normal force (N) acting between the objects. $f_{max} = \mu_s N$ where μ_s is the proportionality constant

This relation gives only the magnitude of f_{max}.

Also, f_{max} is not in the direction of N. **This law is empirical and not derived from any fundamental theory of physics**.

Magnitude of static friction is independent of area of contact so long as the normal force remains the same. The proportionality constant μ_s is called the **coefficient of static friction.** The value of μ_s can lie between zero to infinity i.e. $0 < \mu_s < \infty$. Its value can only be determined experimentally by measuring frictional force f_{max} and normal force N and then by finding their ratio. μ_s has no units, being a ratio of two forces. **The value of μ_s depends on:**

(a) The nature of materials

(b) Nature of surfaces in contact.

μ_s is generally large for rough surfaces and small for smooth surfaces.

The value of μ_k does not depend on frictional force f_k and normal force N.

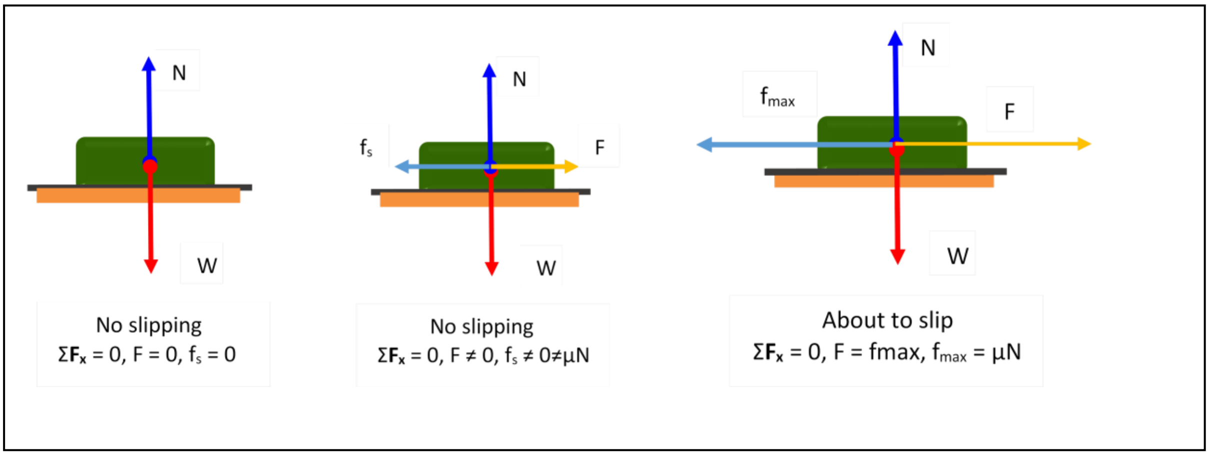
μ_s is generally larger than μ_k.

See the table below:

System	Static friction μ_s	Kinetic friction μ_k
Rubber on dry concrete	1.0	0.7
Rubber on wet concrete	0.7	0.5
Wood on wood	0.5	0.3
Waxed wood on wet snow	0.14	0.1
Metal on wood	0.5	0.3
Steel on steel (dry)	0.6	0.3
Steel on steel (oiled)	0.05	0.03
Teflon on steel	0.04	0.04
Bone lubricated by synovial fluid	0.016	0.015
Shoes on wood	0.9	0.7
Shoes on ice	0.1	0.05
Ice on ice	0.1	0.03
Steel on ice	0.4	0.02

TABLE : Coefficients of Static and Kinetic Friction

Credit: http://passthru.cnx.org/plone/content/m42139/latest/?collection=col11697/latest



CHECK YOUR UNDERSTANDING

EXAMPLE

A block lies on a table. What is the static frictional force between the block and the table?

SOLUTION

Zero

(No force on the block parallel to table surface, hence not tending to rub the table surface)

EXAMPLE

If a horizontal force of 6N is applied on the block in previous question, but the block does not move, what is the magnitude of the static friction on it?

SOLUTION

: 6 N (the friction must counterbalance the applied force)

EXAMPLE:

If the maximum value of static friction on the block is 11 N, will the block move on applying a horizontal force of 9 N? Why?

SOLUTION: No, because friction can increase its value to 9 N to exactly balance the applied force.

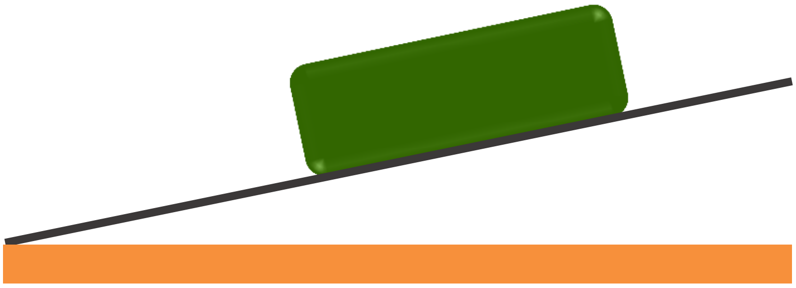
EXAMPLE:

Will the block move on applying a horizontal force of 13 N?

SOLUTION Yes (Friction will not be able to increase its value beyond 11 N)

EXAMPLE:

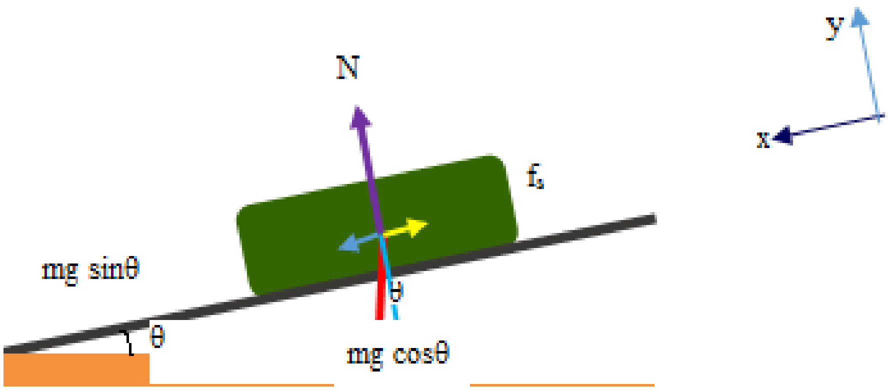
Will there be any static frictional force on the block, if it remains stationary even on raising the table top of the previous question slightly from the right end? See figure below.



SOLUTION: Yes, (Now there is a tendency to slip down, hence it tends to rub the table surface)

EXAMPLE:

What is magnitude of static friction on a block of 30 kg lying stationary on a wooden plank inclined at 10° with horizontal?



SOLUTION 51.04 N

Since block is stationary, there is no acceleration on the block in x as well as y directions. The net force along x-axis must be zero, hence force of static friction counterbalance the component of weight along x-axis.

f_s = mg sinθ = 30 x 9.8 x sin 10° = 30 x 9.8 x 0.1736 = 51.04 N

EXAMPLE:

If the coefficient of static friction between the block and the wooden plank in the question above is 0.5, will the block slip down on increasing the angle of inclination to 20°?

SOLUTION No

Hint: $f_{max} = \mu_s N = mg \cos\theta$

Check if mg $\sin\theta > f_{max}$. If yes, the friction is not sufficient to counterbalance mg $\sin\theta$ and the block will slip, otherwise not.

EXAMPLE:

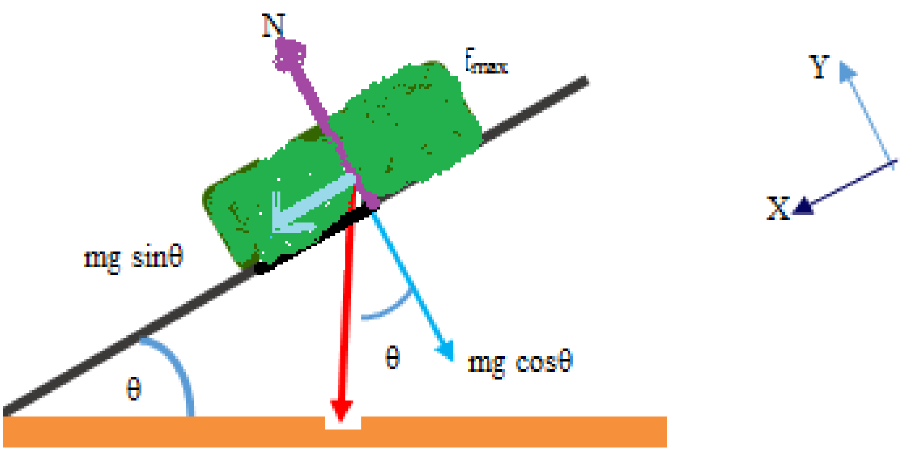
What is the force of static friction acting on the block in the question above?

SOLUTION

110.6 N

Since the block is not slipping down, the magnitude of force of static friction is equal to mg $\sin 20^\circ$.

ANGLE OF REPOSE: The maximum angle of slope at which the upper body will remain in place without sliding.



For the upper body to remain stationary, net force along x and y directions must be zero.

Along x- direction $\Sigma F_x = mg \sin\theta - f_{max} = 0$, hence $f_{max} = mg \sin\theta$ ….. (1)

Along y- direction $\Sigma F_y = N - mg \cos\theta = 0$, hence $N = mg \cos\theta$ ……..(2)

Dividing eq. (1) by eq.(2), we get

$f_{max} / N = \tan\theta$

$\mu_s = \tan \theta$

CHECK YOUR UNDERSTANDING

What can be the maximum steepness of a road so that vehicles can be parked safely, if its wheels are locked and the coefficient of static friction between the road surface and the tyres is 1.0 in dry conditions and 0.7 in wet condition?

Credit: https://en.wikipedia.org/wiki/Baldwin_Street#/media/File:DunedinBaldwinStreet_Parked_Car.jpg

SOLUTION

35

8. FRICTIONAL FORCES CONSOLIDATED

We can consolidate our understanding of static and kinetic frictions as follows:

Friction is a force that impedes motion and usually reduces the net acceleration. It usually does not speed up an object.

Consequence of friction being a force:

If friction is a force, it must obey Newton's third law. That means if body A applies a force of friction on body B, the body B also must apply an equal and opposite force of friction on body A.

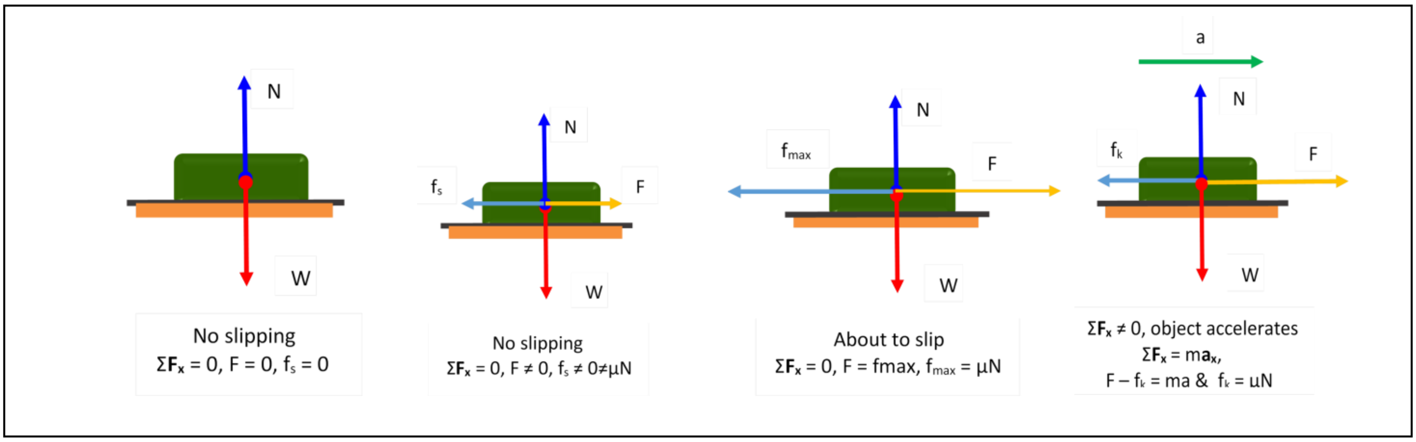
Direction of friction: Always parallel to the surface. If there is no slipping, friction acts in the direction needed to prevent motion. If there is slipping, friction acts in the direction opposite to relative motion.

Magnitude of friction:

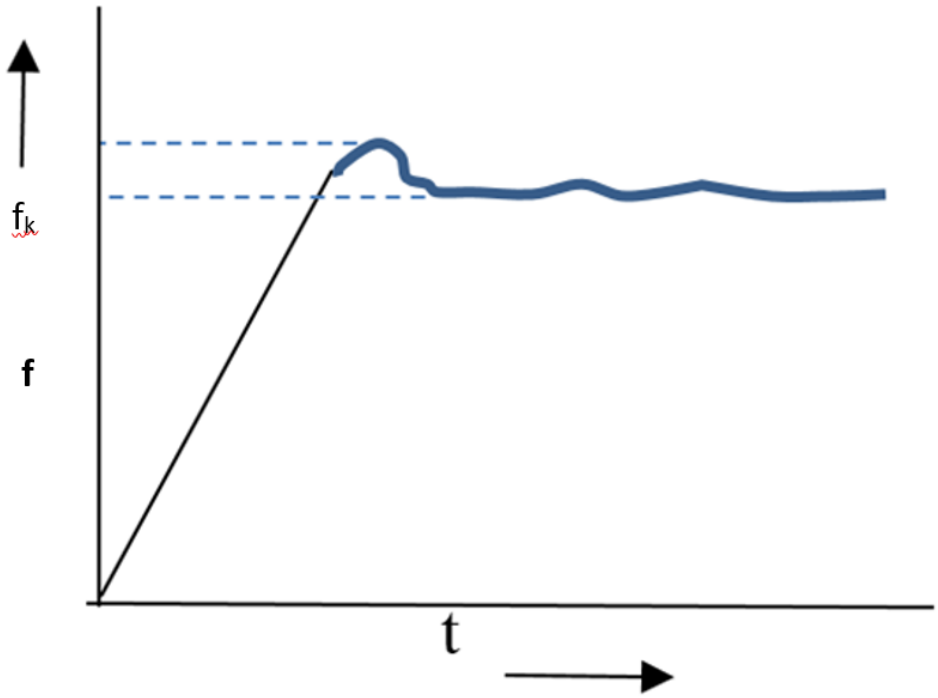
Not slipping: The magnitude of friction force can only be calculated from $\Sigma F = ma$. However, it has a maximum value $f_s \leq \mu_s N$. Just about to slip: $f_s = \mu_s N$

Slipping: $f_k = \mu_k N$

$\mu_k < \mu_s$.



The graph below shows how the frictional force varies with time when an object is pushed over another surface.



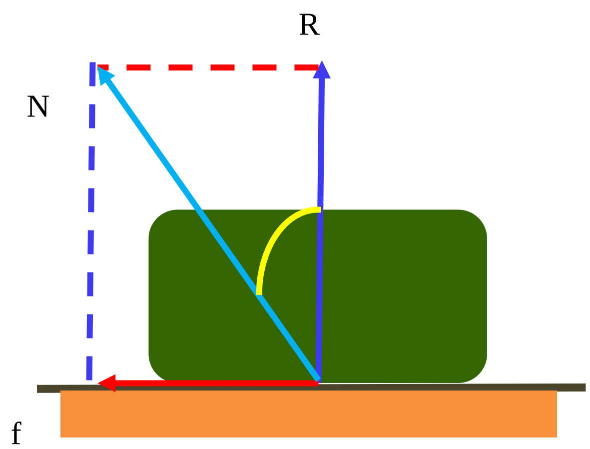
Friction as component of contact force

The normal force N is one component of the contact force between two objects, acting perpendicular to their interface.

The frictional force f is the other component, acting tangentially to plane of the interface between objects.

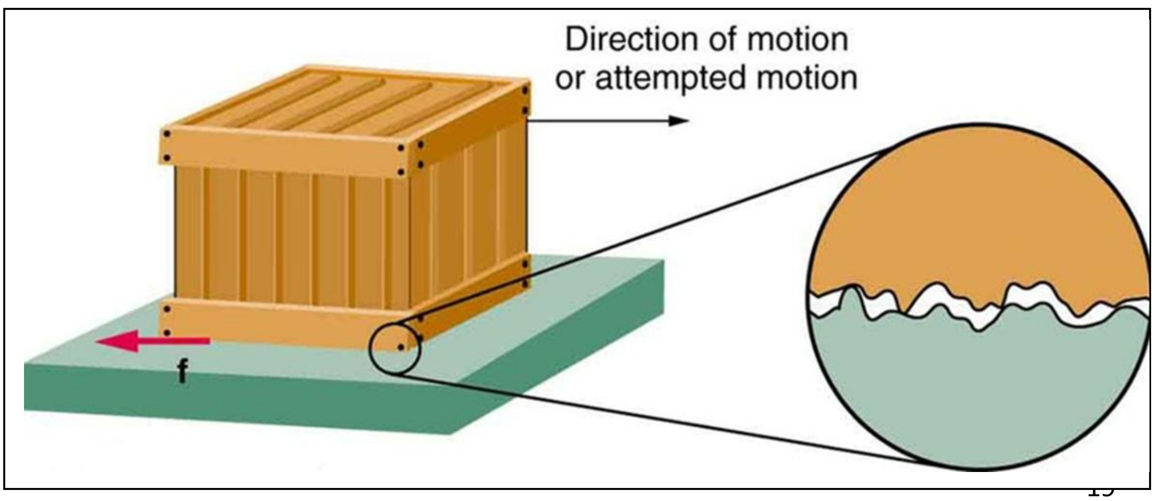
The net contact force R between two objects is the resultant of the two forces.

Angle of friction: the angle between the net contact force R and the normal reaction N on an object is called the angle of friction. It is shown as angle δ in the figure below.



8. UNDERSTANDING FRICTION AT ATOMIC LEVEL

Friction acts between surfaces in contact. Even though surfaces may appear and feel smooth, they contain microscopic peaks and ridges, bumps and pits. When two objects are put together, these bumps and pits on their surfaces fit into each other and particles cling together at the points of contact.

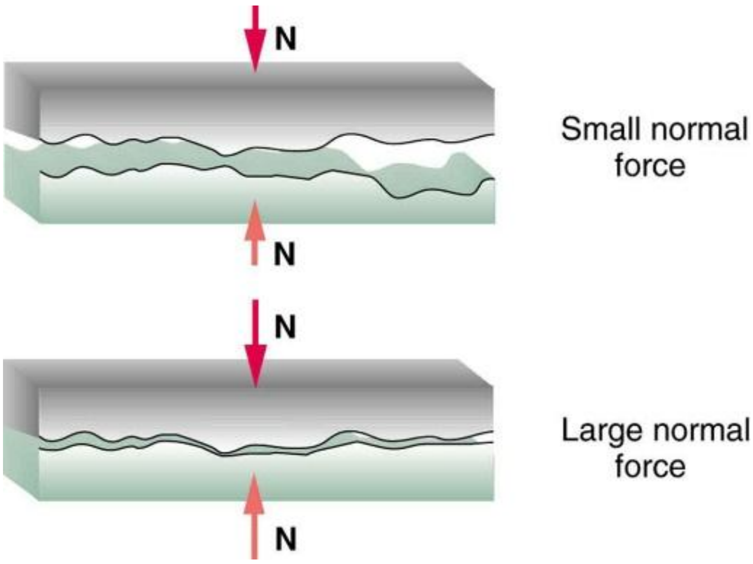


Figure

Credit:
http://www.wheatland.k12.ny.us/webpages/dkrill/imageGallery/Crate%20on%20surface%20friction.jpg

As long as two objects are stationary over each other, the interlocks pose no problem and macroscopically f_s is zero.

When we push one object to move over the other, the interlocks obstruct motion. Force of friction f_s makes an appearance. In order to move, the object must either rise over the bumps posed by the lower surface or scrape off atoms. Either way requires force. Hence more force has to be deployed. If the additional force is not sufficient, the object may still not be able to rise over the bumps nor scrape off atoms and still unable to slide. Friction f_s has increased in magnitude. If we go on increasing the applied force, the opposition offered by interlocks reaches a maximum before giving way. f_{max} has been reached. The strength of interlocks depends on attraction between atoms of two surfaces i.e. the nature of materials in contact. How much they are pressed together i.e. the force perpendicular to the plane of contact or Normal Force N. Whether the interlocks are in the process of being formed.



Figure

Credit: http://passthru.cnx.org/plone/content/m42139/latest/?collection=col11697/latest

The stronger the interlocks, the greater the friction.

As the object rises over the bumps or scraps off atoms and moves forward, interlocks are continuously being released and forming afresh. These are weak and hence friction f_k is less than f_s.

As the interlocks break, local deformation causes vibrations and waves to be set up. This causes the noise between rubbing objects.

Vibrations spreading through waves impart energy to the particles of the surfaces in contact and thus the bodies become heated.

The energy imparted can also causes electron transfer between surfaces and thus bodies become charged.

9. ROLLING FRICTION

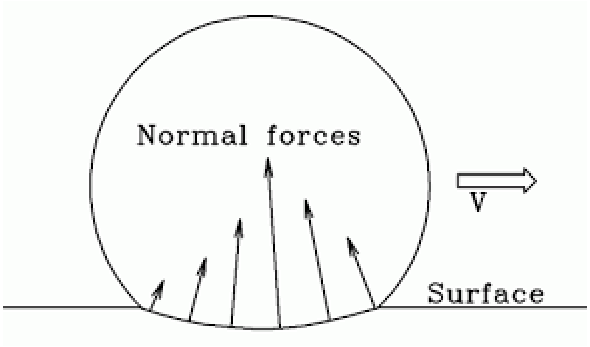
A body like a sphere or ring, rolling without slipping on a surface ideally has just one point of contact with the surface and at this point there is no motion relative to the surface. Hence in this ideal situation there is no static or kinetic friction. The body should roll with constant velocity.

Consider the following:

A child pushes a bicycle tire on the ground. It rolls some distance and then stops. To keep it rolling with constant velocity, the child must push it continuously with a stick.

Credit: http://www.theunrealtimes.com/wp-content/uploads/2014/02/rubbertyre.jpg

Both point to existence of a force that impedes the rolling motion. This force is the force of rolling friction. Rolling friction has a complex origin, somewhat different from that of static and kinetic friction. During rolling, the surfaces in contact get momentarily deformed a little. This results in a finite area (not a point) of the rolling body being in contact with the surface.



Credit : https://www.lhup.edu/~dsimanek/scenario/rolling.htm

This deformation gives rise to uneven normal forces at different points. The resultant of these forces has two components – one parallel to surface and the other perpendicular. The parallel component opposes the slipping and the normal component opposes the rolling. Rolling friction is much smaller than static or kinetic friction for same weight.

This property is used for reducing friction between machine parts. Use of ball bearings between two moving parts of a machine changes the sliding friction to rolling friction which is much lesser. See an animation at the link below

https://upload.wikimedia.org/wikipedia/commons/3/30/BallBearing.gif

Credit:
http://www.generalbearing.com/assets/images/general_bearing_bearing_mfgers.jpg

10. FRICTION IN OUR LIFE:

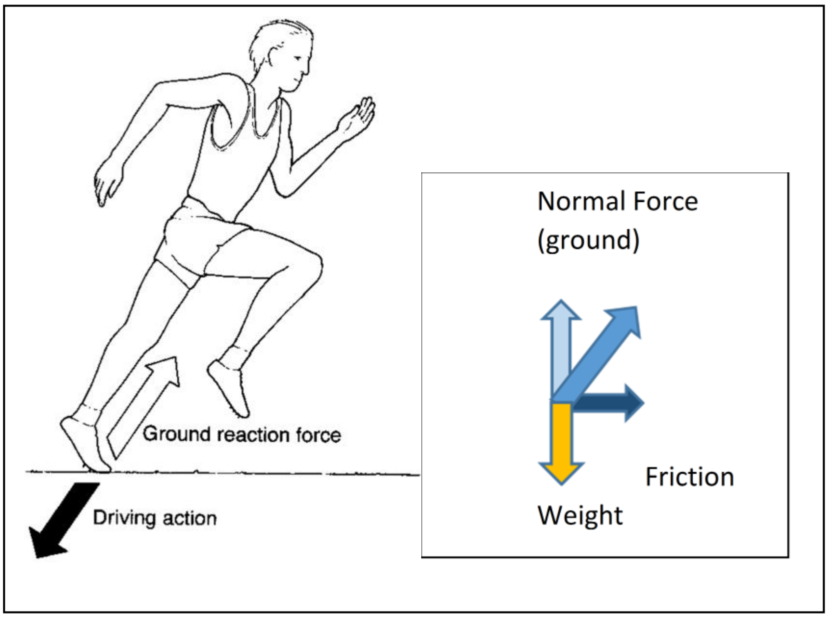
Common occurrences & latest technological advances

(A) FRICTION & MOTION: WALKING

While walking, our foot exerts a backward and downward force on the ground. The ground exerts an equal and opposite force on our foot.

The horizontal backward force is the frictional force applied by our foot on the ground. It is the friction from the ground that drives us forward.

The downward force applied by the foot on the ground has an upward normal reaction from the ground which balances our weight.



Credit: http://www.aaronswansonpt.com/basic-biomechanics-newtons-laws-of-motion/

While walking, or moving any limbs, why don’t our bones rub against each other and wear out? This is because of the synovial fluid produced by the joints which acts as a natural lubricant and reduces friction and wear. Other natural lubricants are the saliva produced in the mouth to help with swallowing and slippery mucus between the organs, allowing easy slipping against each other.

Friction is an important factor in design of artificial joints because ease-of-use, wear and patient comfort are of major concern in use of these devices. Read about science of friction for medical applications here

http://www.medicaldevice-network.com/features/feature52481/

SLITHERING MOTION OF SNAKES

Snakes slither by raising different parts of their body and touching the ground only at few points. At these points they push the ground much like the human feet and friction gives them the required forward push. Watch how the sidewinder moves fast in desert and at the same time, saves itself from scorching heat:
https://www.youtube.com/watch?v=B3NbPUTD5qA

Snakes can slither across flat surfaces or climb up the trees without legs, **because snake scales act as friction hooks which catch in rough points on surfaces** (a new study shows). This important and surprising research shows that snakes can double their friction coefficients by active control of their scales.
Strangely, the research finding could eventually lead to robotic snakes that move more naturally. They could be used to sense life under debris.
Learn about new research in these videos
https://www.youtube.com/watch?v=Ymf_HYG2WdE
https://www.youtube.com/watch?v=ZSHzDesFe6U

FRICTION AND ROAD SAFETY

Friction is an important factor for safe driving on roads, especially in wet conditions or in presence of ice. **Wet roads** and ice have lower coefficients of friction which translate to a longer stopping distance, hence greater chances of collision. A higher coefficient of friction decreases the stopping distance. Therefore, **the material of tyres must have a good grip or higher coefficient of friction with the road**. It is better for car tyres to use static friction rather than kinetic friction to stop the vehicle, since static friction is greater.

If the tyres are rolling along so that the surface touching the ground is never sliding, then static friction acts to slow the car. If the wheels are locked and sliding, then kinetic friction acts to slow the car. For utilizing static friction when quick stopping is required, following options are possible:

Apply just enough braking to stay within the static range of friction and not too much to cause the brakes to lock. This is the best way to stop, but it can be difficult to apply just enough pressure (and not too much) to stop in this manner. To get around this challenge, pump the brakes, which use alternate kinetic and static friction as the wheels lock and unlock, sliding and rolling. Anti-lock braking systems (ABS) on a vehicle prevent the wheels from locking up when the brakes are applied, thus minimizing the amount of time it takes for the vehicle to reach a complete stop. The best solution is simply to drive slower!

MISCONCEPTIONS ABOUT TYRES:

Extra wide tyres do not provide more friction than narrow ones. Friction is independent of surface area! **They simply spread the weight of the vehicle over more surface area and this reduces heating and wear**.

https://pixabay.com/images/search/trailer%20truck/

Greater no of tyres does not reduce friction, nor it reduces the stopping distance. They only reduce the pressure per tyre and the wear. Tyres have treads not to decrease friction but to provide channels to which water can be redirected from beneath the tires and through which water can flow.

(B)FRICTION AND VIBRATIONS

We learnt earlier how friction produces vibrations which travel as waves and can result in sound being produced. Friction-excited vibrations are common to our sonic environment - brake noises, chalks on blackboards, chairs sliding on hard floor, screeching sounds of car tyres on road, the sound of machines in factories etc. But this property of friction has many interesting and more appealing applications, friction music being one of them. Enjoy watching some amazing instruments being played at these links

Glass harp: https://www.youtube.com/watch?v=XKRj-T4l-e8
Tibetian singing bowl: https://www.youtube.com/watch?v=6ZV1ek0yKTU
Glass Armonica: https://www.youtube.com/watch?v=eEKlRUvk9zc
Friction Harp: https://www.youtube.com/watch?v=g4i2mzQqNRY
Friction drums: https://www.youtube.com/watch?v=dVOm268uQkw
Musical saw: https://www.youtube.com/watch?v=wsv0sT5HgR4
A musical fun at https://www.youtube.com/watch?v=tIIJME8-au8
Frictional motion study could provide tool for earthquake prediction. Read more at http://phys.org/news/2004-09-frictional-motion-tool-earthquake.html

(c) FRICTION AND HEAT

We understood earlier how friction produces heat. This property can be used to transfer energy from one surface to another. Primitive man tapped this property of friction to ignite fire.

Watch the video here https://www.youtube.com/watch?v=V1MS0uBrgFA
This property of friction is used in modern times like weld metals together. Watch the videos at: https://www.youtube.com/watch?v=5JbnDXw-0pM

and https://www.youtube.com/watch?v=iG3t0Q7UuCU

It is also used for drilling holes as shown here https://www.youtube.com/watch?v=NhkWINPRK3A

Friction produces heat between machine parts. They must be constantly cooled to safeguard against permanent damage. For example, while cutting concrete the drill must be cooled with water. Watch the videos here

https://www.youtube.com/watch?v=i6yaTFA_a_w

https://www.youtube.com/watch?v=JDds3bOL1S8

(d) FRICTION & AMAZING NEW AGE TECHNOLOGIES

Amazing Touch screen technology for 3D sensation based on the electrovibration principle, which can programmatically vary the friction between sliding fingers and a touch panel.

Watch here http://www.olivierbau.com/teslatouch.php

Read more about it here: http://discovermagazine.com/2015/june/17-hooked-on-a-feeling

Understanding how to reduce friction has given rise to mind blowing future transport technology. Watch a video here:
https://www.youtube.com/watch?v=oYOmZlTjsQ0

Smart materials with high friction which can enable competing with Spiderman!
https://www.youtube.com/watch?v=gzm7yD-JuyM

Materials slicker than Teflon!

https://www.newscientist.com/article/dn16102-material-slicker-than-teflon-discovered-by-accident/

12. SUMMARY

- Friction is a force that impedes motion and produces vibrations, heat and electricity.
- Friction is the parallel component of contact force between surfaces.

- Static friction is the force opposing the intended slipping between two stationary surfaces.
- Kinetic friction is the force opposing the relative motion between moving surfaces.
- Direction of friction: Always parallel to the surface, If there is no slipping, friction acts in the direction needed to prevent motion, If there is slipping, friction acts in the direction opposite to the motion.
- Magnitude of friction: Not slipping: The magnitude of friction force can only be calculated from $\Sigma F = ma$. However, it has a maximum value $f_s \leq \mu_s N$.

Just about to slip: $f_s = \mu_s N$

Slipping: $f_k = \mu_k N$

$\mu_k < \mu_s$.

- Irregularities in surfaces at atomic level and molecular forces cause friction.
- Rolling friction is the friction that opposes rolling motion of an object over another.
- Countering friction can be a challenge but at the same time its properties can be used for our advantage. It has important applications in road safety, comfortable use of artificial joints, welding of materials, musical instruments, reduction of noise and many modern technologies.

Credits:

Figure 1

Picture 1:
http://www.publicdomainpictures.net/pictures/60000/velka/praying-hands-1379173607ePZ.jpg

Picture 2:
https://www.google.co.in/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=0ahUKEwjbyuLmxvfNAhVEr48KHUwjBRIQjRwIBw&url=http%3A%2F%2Fwww.shutterstock.com%2Fs%2Frubbing%2Bhands%2Btogether%2Fsearch.html&psig=AFQjCNHHWMnYxW817zRLqw3QjPUJEJHBqg&ust=1468743701691758

Picture 3:

https://www.google.co.in/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=0ahUKEwjVrbzemvfNAhXLMY8KHYUUB6EQjRwIBw&url=https%3A%2F%2Fyogatraveltree.com%2Farticle%2F5-yoga-poses-balance-third-eye-chakra%2F&bvm=bv.127178174,d.c2I&psig=AFQjCNEVHieV_tNNc06ZeH8ttP8DvQ0-Mg&ust=1468731826509996

Picture 4:

https://upload.wikimedia.org/wikipedia/commons/thumb/b/b4/Krumkake_rolling_1.jpg/1599px-Krumkake_rolling_1.jpg