**Basics of Mechanical Engineering-1**

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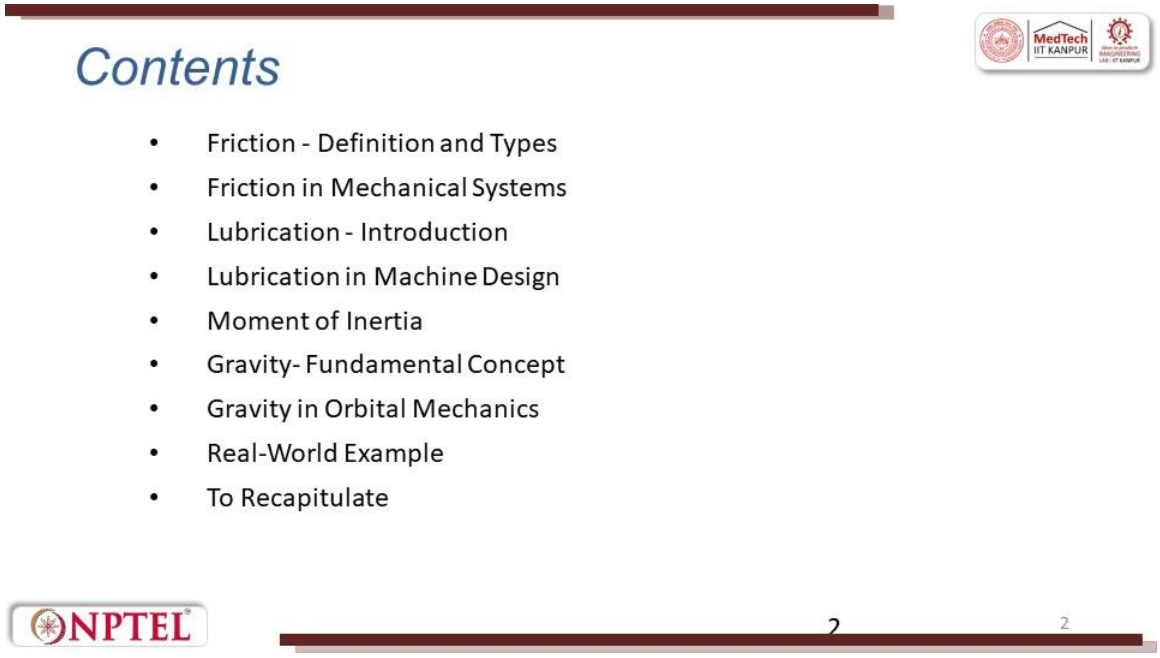
**Week 02**

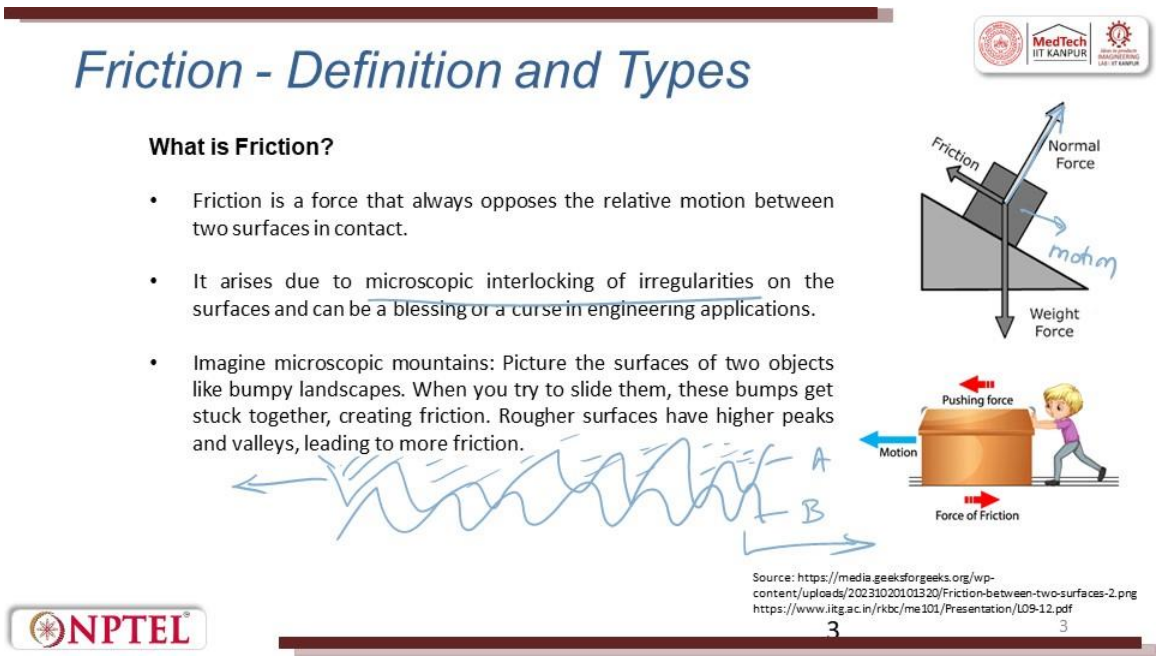
**Lecture 06**

**Friction and Lubrication**

Welcome to the next lecture in our course. In this lecture, we will be trying to cover Friction and Lubrication.




The content of this lecture, first we will see the definition of friction. There are various Types of Friction. We will see them in detail. Then friction in mechanical engineering systems. Then you will see Lubrication. Lubrication in machine design, moment of inertia, gravity, fundamental concepts, then gravity in orbital mechanics, real world examples, recap, and then we will try to have one or two problems which will allow you to think out of the box.




What is Friction? Friction is a force that always opposes the relative motion between two surfaces in contact.

So, if you see here, there is a weight. Convert this weight into a truck. It is staying on the bridge and it is coming down the bridge. So, when it is moving down, you will see the normal force is perpendicular to this or the normal force is acting along this direction of the vehicle will be acting down. There will be tires which are moving and the friction will be in this direction.

The same condition can happen in metal cutting also. You can have a tool, on top of the tool the chip flows, almost a similar situation. So, when we have to analyze the force which is required, we resolve the normal force, weight force and the frictional force to find out what will be the cutting force at that situation. But here we are trying to make it simple, a truck moving down, normal force, weight force and friction force. It arises due to microscopic interlocking of irregularities of the surface and can be a blessing or a curse in engineering application.

For example, if you are trying to walk with absolute zero friction, you will always fall down or you will just be sliding. The friction puts a restriction on the movement and that tries to give you stability and while walking it makes you comfortable. So, when you try

to press both of your hands and try to move, you will see there is lot of heat getting generated. This heat is nothing but the friction which is there between the two hands. So, friction is very important.

Friction can be used as a blessing or it can be used as a curse. Because when we start having two mating surfaces and when it is sliding, rolling, when the gears are in mesh, you will see friction dominates. This friction leads to wear. So, the wear tries to underperform the system. So, friction is also a curse. Imagine microscopic mountains. What are we trying to example?

So let us assume these are mountains, right. And then you are having one more mountain. Let us take it on the other way, this way. This is another mountain. This is A and this is B, okay. So, picture the surface of two objects A and B like a bumpy landscape. When you try to slide them in this direction, these bumps get stuck in the interlocking, creating friction and the rougher surface have higher asperities, peaks and valleys leading to more friction.

That is why we always try to work on, reduce the asperities which are there on the surface, so that you get a smooth flat surface. When you have smooth flat surface, these bumps will not be there, the friction will be reduced. So, processes like grinding, honing, finishing, burnishing, these are some of the processes wherein which they are used for removing these asperities. So, when you remove these asperities, two surfaces can smoothly slide. So, you can see here, a boy is trying to push a box. This is the pushing force.

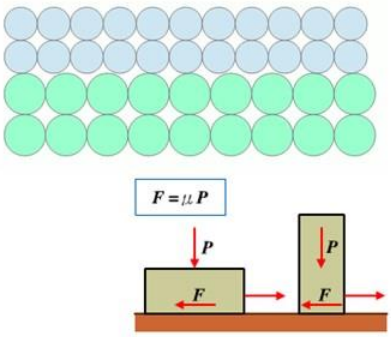
You see the friction force will be in the opposite direction, friction force and the motion. So, if you see here also, the motion will be in this direction because I told you it is a bridge, bus is coming down or a lorry is coming down. So, types of friction.

# Friction - Definition and Types

**Types of Friction**

**Dry Friction (Coulomb Friction):**

- Occurs when unlubricated solid surfaces are in contact with relative motion or a tendency to slide, producing a friction force that opposes motion.
- Based on Coulomb's and Morin's experiments, it is used to handle most dry friction problems.




Source: https://dry-friction.com/wp-content/uploads/2020/11/Animation.gif
https://semesters.in/coulombs-law-of-friction-btech-first-year/



The first friction what we are trying to talk about is dry friction. Dry friction is otherwise called as Coulomb friction. It occurs when unlubricated solid surfaces are in contact with relative motion or a tendency to slide producing a friction force that opposes the motion. Based on Coulomb's force and Morin's experiment, it is used to handle most dry friction problems.

So, you will see here F is nothing but mu times P where mu is the friction force. So, P is the load which is applying and when you are dragging it, the friction comes in this direction. So, when you have an object which is, this is larger width object, this is a smaller width. So, it also has P downward, F in this direction and this direction you are pulling.

## Friction - Definition and Types

**Fluid Friction:**

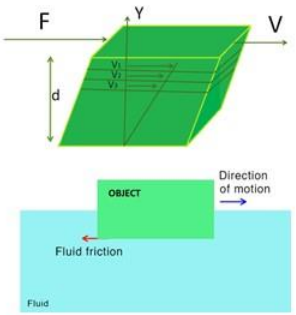
Happens when different layers of a fluid (liquid or gas) move at varying velocities, creating frictional forces dependent on relative velocity and fluid viscosity. It is studied in fluid mechanics.

The amount of fluid friction depends on several factors, including:

- Viscosity of the fluid: Thicker fluids, like honey, have higher viscosity and thus more friction.
- Shape of the object: Streamlined objects experience less friction than blunt objects.
- Speed of movement: Friction generally increases with speed.

**Internal Friction:** ⇒ material related.

It is a term not typically used in classical mechanics but can be related to the concept of material deformation. When a solid material undergoes stress (force), it can deform slightly. This internal resistance to deformation can be thought of as a type of friction within the material itself. However, it's not usually categorized as a separate type of friction in mechanical engineering.

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5

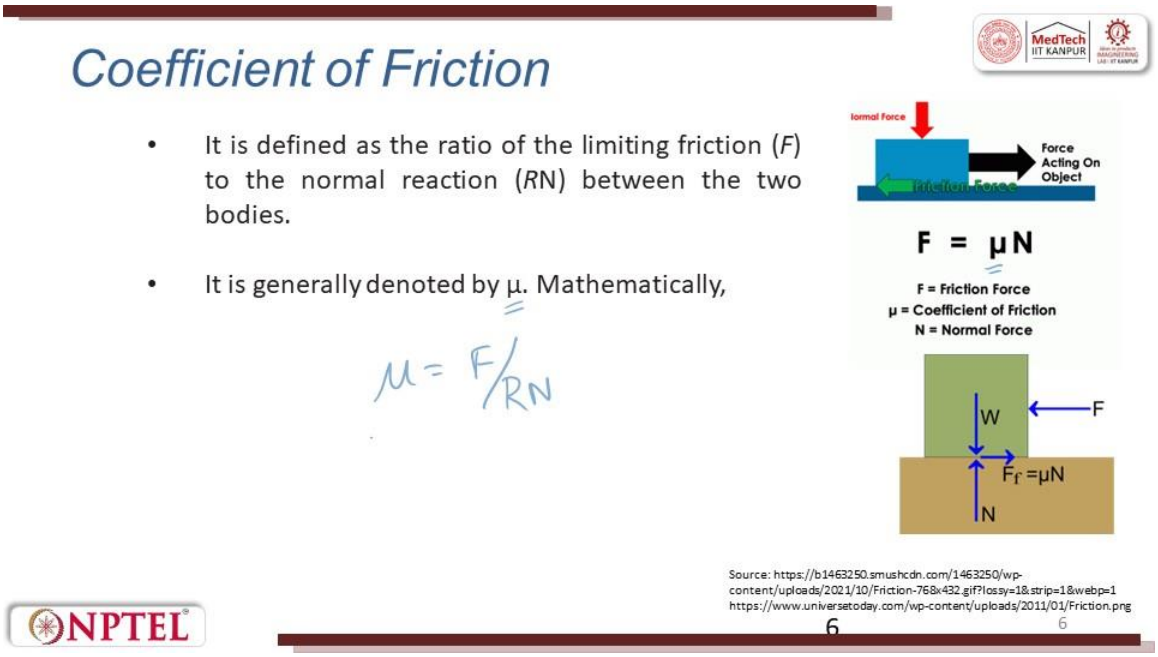
The second thing is called as Fluid friction. It is very important in the field of fluid engineering, aerospace engineering, chemical engineering and people who work on process technology. Fluid friction is a very, very important terminology. This happens when different layers of fluid move at varying velocities.

For example, layers we are saying assume that you have a stack of cards. Each card is a layer. Now when you try to push one card on the top the bottom, you are holding it pushing it from the top most card slides and next to it there is a relatively lesser movement and it goes on, so here when in fluid what happens, we assume different layers are moving at different velocities creating a frictional force. Why is it happening? Because the top plate is moving, bottom plate is fixed. So, there is a resistance from here.

So, there will have different velocities. Moves at varying velocities creating frictional force depends on relative velocity and fluid viscosity. It is studied in detail in fluid mechanics. The amount of fluid friction depends on several factors. So, viscosity of the fluid means thicker fluid like honey have higher viscosity and thus more friction as compared to oil, honey is more viscous as compared to water, oil is more viscous.

Shape of the object also plays an important role, shape of the object streamline. Objects experience less friction than blunt objects. The speed of movement is also very important. Friction generally increases with speed. So, this is fluid friction. You also have Internal friction.

Internal friction is a term not typically used in classic mechanics but can be related to the concept of material deformation. When a solid material undergoes force, it can deform slightly. For example, you have a ball, you have a hammer, you hit the hammer on the ball, there is a dent which happens. This internal resistance to deformation can be thought of as a type of friction within the material. However, it is not usually categorized as a separate type of friction in mechanical engineering. So, this internal friction is more of material related.




So, coefficient of friction μ, right, it is defined as a ratio of the limiting friction (F) to the normal reaction (RN) between the two bodies, bus or your hand or you put a vessel wherein which you have filled up with oil, you're or a gunny bag, you are trying to slide the gunny bag. So, force acting on the object is sliding. The normal force falls on top of it. Then you will have a friction which is against the force.

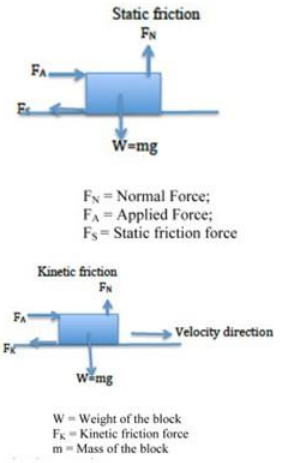
So generally, coefficient of friction is represented as a character called μ. So, $\mu = \frac{F}{RN}$. If you look at this you see the weight which comes down, the normal force which goes against the weight, you have a friction which comes in this direction. So now what are you trying to do is, you are trying to push the object. So here it was pulling, here it is pushing.

So, you are trying to push, you see the weight falling down, normal force going up and the friction force in this direction.

# Laws of Friction

**Amonton's Laws of Friction:**

- **1st Law:** The force of friction (F) is directly proportional to the normal force (N) acting between the surfaces in contact.
- (F ∝ N) This essentially states that the greater the force pressing the surfaces together, the higher the friction force.
- Think about pushing a heavy box versus a light one – more normal force due to weight leads to more friction.

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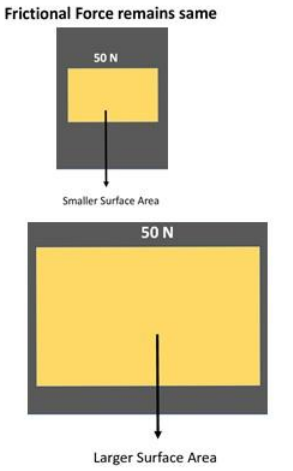
There are different laws of friction. So let us see the different laws of friction. Amonton's law of friction. The first law, (F ∝ N).

So, you have a body. So, in this body what happens is you try to see W which is weight mg which is in the downward direction normal force which is against it. Then you have a pushing force which is there and the friction force which come into existence. F ∝ N. This essentially states that greater the force pressing the surface together, the higher will be the friction force. Think about pushing a heavy box versus a lighter one. More normal force due to weight leads to more friction.

## Laws of Friction

**Amonton's Laws of Friction:**

- **2nd Law:** Friction is independent of the apparent area of contact, as long as there's a sufficient contact area.
- (F ≠ A) Surprisingly, the size of the contact area doesn't significantly affect the frictional force, as long as there's good contact.
- Imagine a box resting on a small or large area of the floor – the friction force to slide it might be similar.

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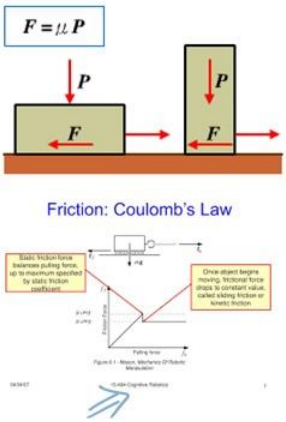
Then we move on to the second law, Friction is independent of the apparent area of contact as long as there is a sufficient contact area. So, the friction force remains the same for this object and for this object. That is what second law says, F ≠ A.

Surprisingly, the size of the contact area does not significantly affect the friction force as long as there is a good contact. Imagine a box resting on a smaller or a larger area of the floor. The friction force of sliding is, it might be similar.

## Laws of Friction

**Coulomb's Law of Friction:**

- This law focuses on Kinetic Friction, the friction experienced by objects already in relative motion.
- It states that the force of kinetic friction (Fk) is directly proportional to the normal force (N) and a constant called the coefficient of kinetic friction (μk).
- (Fk = μk * N) The coefficient (μk) is a material property that depends on the surface textures in contact.
- It is a constant value for a given material combination, regardless of the sliding velocity.



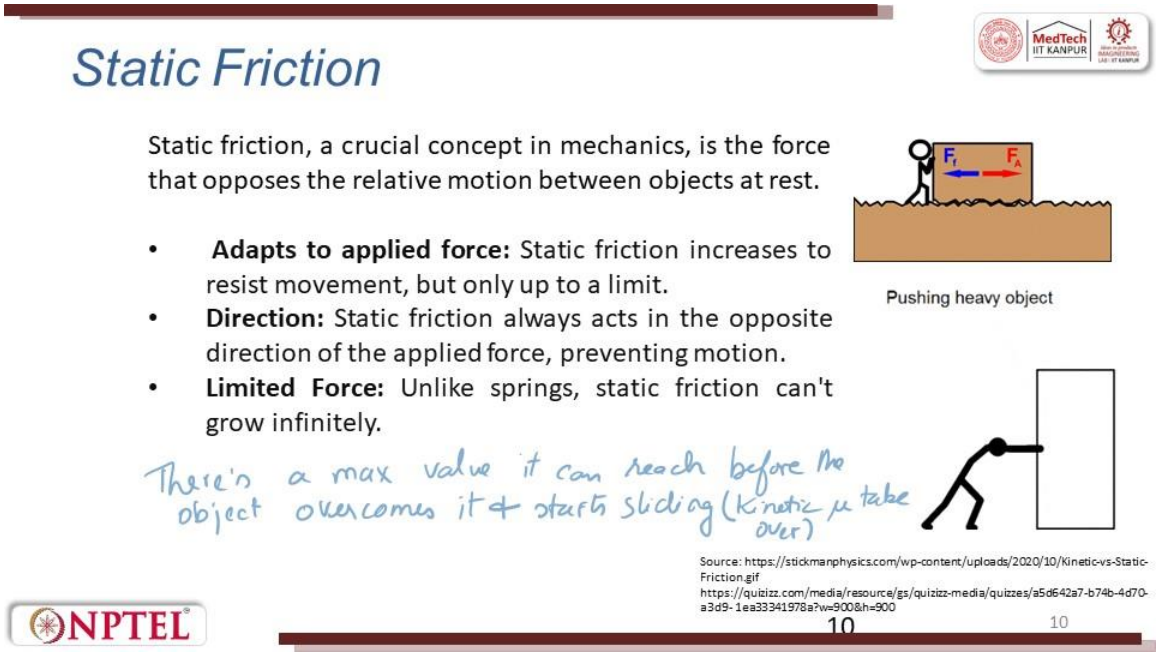

Source: https://www.slideserve.com/nikita/friction

So now let us move to Coulomb's law of friction. This law focuses on Kinetic friction. What is Kinetic friction? There is a Relative motion. So kinetic friction, the friction experienced by objects already in relative motion. There is a motion which is happening and you are trying to find out the friction. It states that the force of kinetic friction (Fk) is directly proportional to the normal force (N) and a constant called as coefficient of kinetic friction.

So ($Fk = \mu k \times N$). The coefficient (μk) is a material property that depends on the surface textures in contact. Please note this point. It is a constant value for a given material combination regardless of the sliding velocity. So, the same picture is repeated, P is the weight, F is the friction force, you are pulling it in this direction.

So, if you look at the Coulombic friction, so we have represented it here nicely. Static friction, so till now what did we saw? We saw first law, second law, second law says that it does not depend on the area. Then we saw kinetic friction.

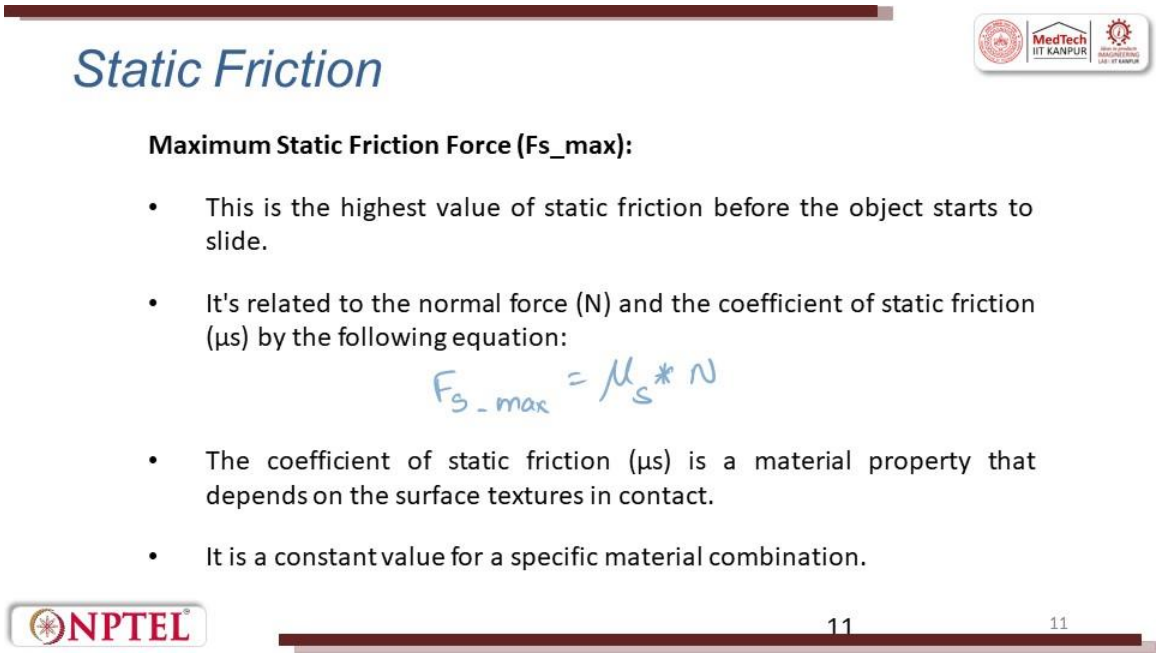
Kinetic friction, it says that regardless of the sliding velocity, it is a constant for a given material combination. So, this figure is important for you to understand.



Static friction is a crucial component in mechanics. The force that opposes the relative motion between objects at rest. Here it adapts to applied force.

Static friction increases to resist movement but only up to a limit. For example, you have a gunny bag which is put on the floor. You are trying to pull. You will keep on the applying force. It will stay in the existing position till the time it reaches a critical point then starts moving. That is what we are trying to say.

Static friction always acts in the opposite direction of the applied force preventing motion. What is a limiting force? Unlike springs, static friction cannot grow infinitely. Therefore, there is a maximum value it can reach before the objects or the object overcomes it and starts sliding. Kinetic friction takes over from here, ok.




So maximum static friction (Fs_max), this is the highest value of static friction before the object starts to slide.

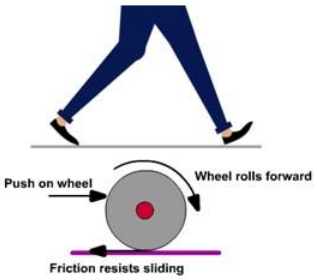
It is related to the normal force and the coefficient of static friction mu s by the following equation. So, $(Fs = \mu s \times N)$. The coefficient of static friction (μs) is a material property that depends on the surface texture in contact. It is a constant value for a specific material combination.

## Static Friction

**Examples:**

- **Walking:**

When walking, static friction between your shoes and the ground allows you to push off the ground and move forward. Without static friction, your feet would slip.




- **Car Tires on a Road:**

Car tires rely on static friction to grip the road when the car is accelerating or decelerating. Static friction provides the necessary traction to move the car forward or stop it.

Source: https://www.electronicsteacher.com/succeed-in-physical-science/friction/frictionrolling_start-push.gif
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So, examples and importance of friction. As I told you, walking happens. It's because of friction. When walking, static friction between your shoe and the ground allows you to push off the ground and move forward. Without static friction, your feet will slide. Let's take an example of a car or a wheel which is rotating or rolling on a flat plane. A car tyre relies on static friction to grip the road when the car is accelerating or decelerating.

The static friction provides the necessary traction to move the car forward or to stop. So, this also happens because of static friction.

## Kinetic Friction

The frictional force that opposes the relative motion of two surfaces sliding past each other

**Characteristics of Kinetic Friction**

- Acts between moving surfaces: Kinetic friction only arises when two objects are already in contact and moving relative to each other.
- Opposes motion: The force of kinetic friction always acts in a direction opposite to the motion of the object.
- Magnitude depends on normal force: The greater the normal force (the force pressing the surfaces together), the greater the force of kinetic friction.



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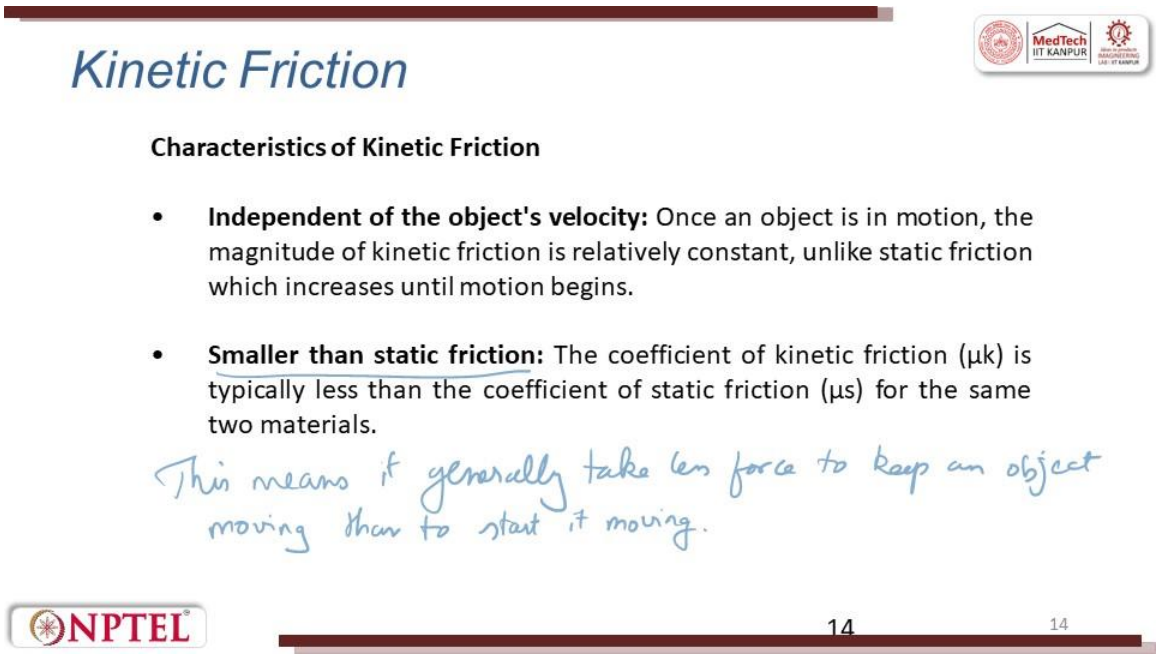
Now, let us look into Kinetic friction. Kinetic friction, the frictional force that opposes the relative motion of two surfaces sliding past each other is kinetic friction. An example of car sliding, it is like a ball getting pushed or you have this rolling game where a ball is rolled and it hits the bottles.

So, these are all examples, ball starts moving. The characteristics of kinetic friction acts between moving surface. Kinetic friction only arises when two objects are already in contact and moving relative to each other. These are the characteristics. Opposite motion, the force of kinetic friction always acts in the direction opposite to the motion of the object.

The magnitude depends on the normal force. Greater the normal force, the greater the force of kinetic friction. These are some of the characteristics.




So, it is independent of object's velocity. Once an object is in motion, the magnitude of the kinetic friction is relatively constant unlike static friction which increases until the motion begins.

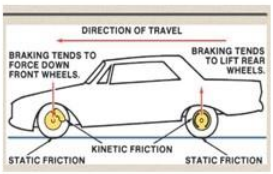
It is always smaller than the static friction. So, this is a hint. The coefficient of kinetic friction is less than the coefficient of static friction for the same two material combination. So, this means, it generally takes less force to keep an object moving than to start it moving. So, when you start a car, the friction will be more.

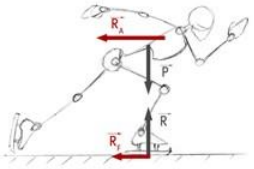
When the car is already moving, it is less. This means it generally takes less force to keep an object moving as compared to that of a starting or a static one.

## Kinetic Friction

**Examples:**

- **Braking a Car:** When the brakes are applied in a moving car, the friction between the brake pads and the rotors (or drums) is kinetic friction, which helps to slow down the car.
- **Ice Skating:** The friction between the ice skates and the ice is an example of kinetic friction, allowing the skater to glide smoothly over the ice.
- **Dragging a Sled:** Pulling a sled over snow involves overcoming kinetic friction between the sled's runners and the snow.



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15

So, examples of kinetic friction. Braking a car. When the brakes are applied in a moving car, the friction between the brake pad and the rotor is kinetic friction which helps to slow down the car.

Ice skating is also kinetic friction. The friction between the ice skates and the ice is an example of kinetic friction, allowing the skater to glide smoothly over the ice. Dragging a sled Pulling a sled over snow involves overcoming kinetic friction between the sled runner and the snow.

## Friction in Mechanical Systems

**Applications:**

- **Brake Systems:**
- Use friction to stop or slow down a vehicle.
- Kinetic friction between brake pads and rotors.
- **Clutches and Belts:**
- Transmit power through frictional contact.
- Kinetic friction ensures effective power transfer.



The other examples of friction in mechanical systems are going to be braking system. We have seen where in which the use of friction to stop or slow down a vehicle, kinetic friction between brake pad and the rotor clutch and the belt, which is there. Again, clutch and belt transmission power through frictional contact kinetic friction ensures effective power transmission or power transfer. So braking system, clutch and belts.

## Friction- Numerical

Determine the maximum angle $\theta$ which the adjustable incline may have with the horizontal before the block of mass m begins to slip. The coefficient of static friction between the block and the inclined surface is $\mu_s$.

Equilibrium in the x & y direction requires

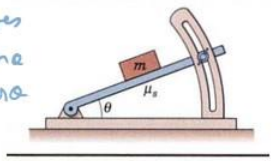
$\sum F_x = 0 \quad mg\sin\theta - F = 0 \; ; \; F = mg\sin\theta$

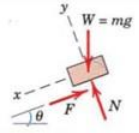
$\sum F_y = 0 \quad -mg\cos\theta + N = 0 \; ; \; N = mg\cos\theta$

$F/N = \tan\theta$.

Since max angle occurs when $F = F_{max} = \mu_s N$, for impending motion

we have $\mu_s = \tan\theta_{max}$ or $\theta_{max} = \tan^{-1}\mu_s$




Source: https://uotechnology.edu.iq/dep-electromechanic/typicall/lecture%20interface/lecture/pwr1/mechanics/mechanics-static-lec6.pdf

Now let us see an example, a problem to solve in friction. So, determine the maximum angle and which the adjustable incline may have with the horizontal before the block of mass M begins to slide. The coefficient of static friction between the block and the inclined surface is μs. So, the first thing what you are supposed to do is draw the free body diagram. So, in the free body diagram, you see that the weight is acting down mg. So, the normal force and the friction force, the normal force is in this direction, friction force is in this direction opposite.

This is a friction force, normal force. Of the two things are of the weight, normal force of the inclined object is N, the friction force is F. The friction force acts on the direction opposite to the slipping which would occur if no friction were present. So, the angle which is inclined is θ.

So, the equilibrium in the x and y direction requires,

$$\sum F_x = 0 \qquad mgSin\theta - F = 0; \quad (F = mgSin\theta)$$
$$\sum F_y = 0 \qquad -mgCos\theta + N = 0; \quad (N = mgCos\theta)$$

So, when we try to find out the first equation by the second equation,

$$\frac{F}{N} = tan\theta$$

Since maximum angle occurs when

$F = F_{max} = \mu_s N$ for impending motion,

$$\mu_s = tan\theta_{max} \; or \; tan\theta_{max} = tan^{-1}\,\mu_s.$$

So, if you look into the problem there is a block. The block is trying to slide down. So, you are trying to find out what is the maximum angle in which the adjustable inclined plane may have with the horizontal plane before the block starts slipping.

## Lubrication - Introduction

**What is Lubrication?**

- Lubrication is the process of reducing friction and wear between surfaces in relative motion by introducing a lubricant.
- The primary purpose is to minimize heat generation, wear, and energy consumption by creating a thin film that separates the contacting surfaces.

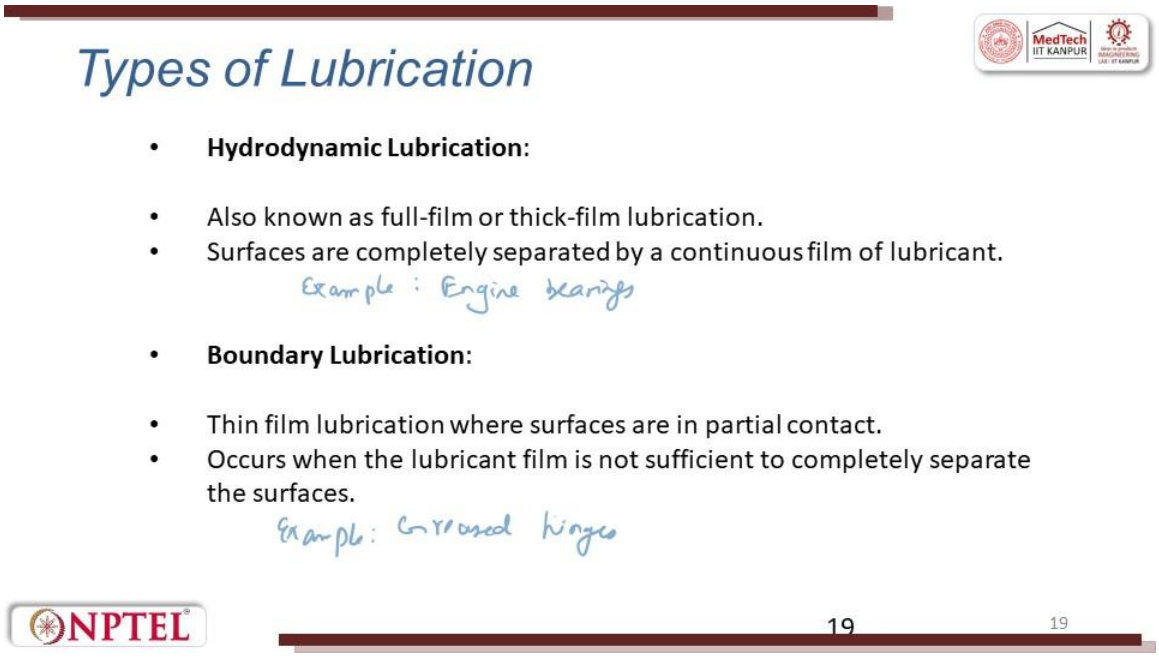

Source: https://media.noria.com/sites/Uploads/2018/3/25/b711d308-5a18-49e6-b09d-175939c9ab3f_lubrication-basics-660_extra_lare.jpeg
https://nexxis.com/wp-content/uploads/sites/3/2020/06/egffective-machinery-lubrication.jpg



Now, let us move towards another topic which is lubrication. When friction comes, friction is a bless as well as a curse. When there is a friction as a curse, what we do is we would try to reduce the curse by getting into a topic called Lubrication. Lubrication is a process of reducing friction. So that is why even in your cycle when you are driving, when you are riding your bicycle, you will listen to creaking noise. If you want to reduce it, we always try to put oil between the chain and the driving wheel or between the brakes, wherever there is a mechanical component, whereas there is a sliding friction, we try to put oil there.

When we try to place oil there, it is nothing but a process of lubrication. Lubrication is a process of reducing friction and wear between the surface in relative motion by introducing a liquid which is nothing but a lubricant. In cars, we pour oil between the gears, so that also reduces friction. The main purpose is to minimize the heat generated wear and energy consumption by creating a thin film that separates the contacting surface. So, when there is an asperity, when there are asperities between this you try to fill it up with a liquid.

So, that process is called as Lubrication. You can fill it with liquid or you can fill it with water or you can fill it with grease. The only difference between all the three is the viscosity of the lubricant.

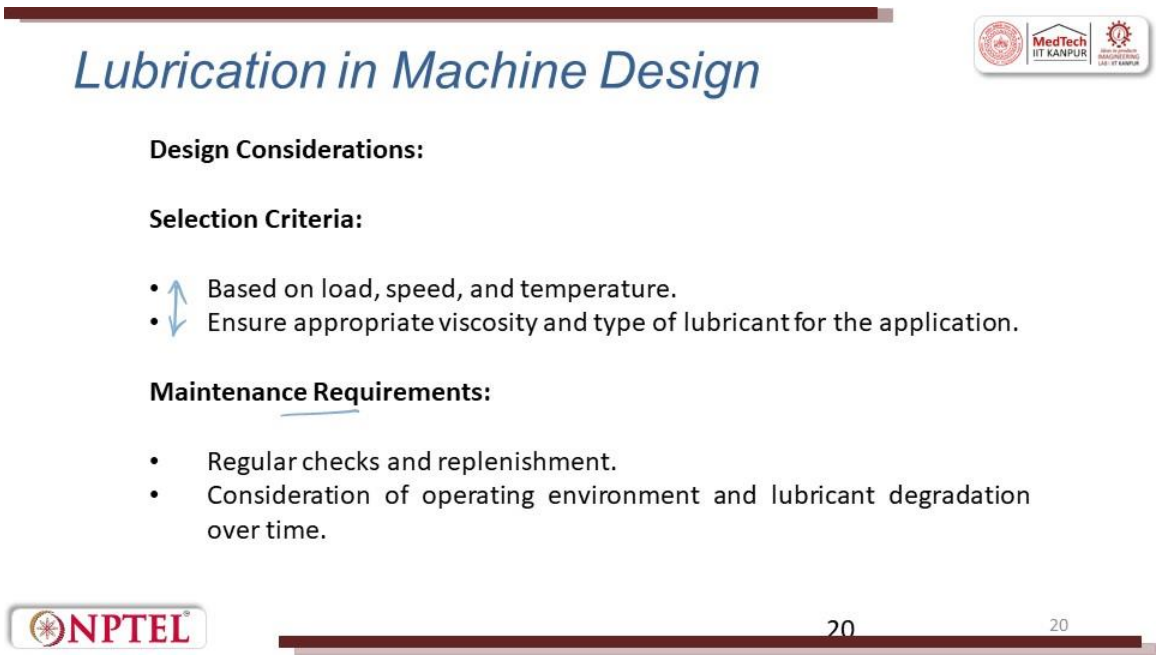



So, in lubrication, you have hydrodynamic lubrication, boundary lubrication. Hydrodynamic also known as full film or thick film lubrication.

Here, the surfaces are completely separated by a continuous film of lubrication. Example, you have engine bearings. So, a full film or a thick film of lubrication is there. There boundary lubrication is opposite of it which is a thin film lubrication where surfaces are in partial contact. This occurs when the lubricant film is not sufficient to completely separate the surfaces.

Why cannot it completely separate the surfaces? May be the loads are very high. So, what is the example? Example are greased hinges. It is an example. So, when we are trying to put dosa also what we do is we pour oil first.

The oil first is acting like a lubricant. So, which will help you to erase. Same when we do with chapati. When we try to put oil, it is nothing but which tries to distribute the heat and also tries to reduce the friction between the chapati and the hot plate.




So, there are some design considerations for lubrication in machine design we follow. So, the selection criteria are based on this, based on load, speed and temperature. It also ensures that appropriate viscosity and the type of lubricant for application. Lubrication is always important part of maintenance.

So, the maintenance requirement are regular checks and replenishment consideration of operating environment and lubricant degradation over time are some of the maintenance requirements for lubrication.

Thank you very much.