# Applied Physics 1

## Friction

## 1. Concept of Friction

Friction is defined as the opposing force that comes into play whenever one surface moves, or tends to move, over another surface with which it is in contact. Friction always acts in a direction opposite to the direction of relative motion, or the tendency of relative motion, between the two contacting surfaces.

Friction arises mainly due to the microscopic irregularities (tiny hills and depressions) present on every surface, however smooth it may appear. When two surfaces are pressed together, these irregularities interlock, and additional molecular forces of attraction act between the surfaces, together giving rise to the resisting force called friction.

Friction plays a dual role in daily life and engineering:

- It is necessary and useful in situations such as walking, writing with a pen, the functioning of brakes in vehicles, and the grip between the tyres of a vehicle and the road.
- It is undesirable in situations such as the sliding of machine parts, where it causes wear and tear, generates heat, and results in the wastage of energy that could otherwise be used productively.

## 2. Types of Friction

Depending on the state of relative motion between the two contacting surfaces, friction is classified into the following types:

| Type of Friction | Description |
|---|---|
| Static Friction | The opposing force that comes into play when a body is at rest but a force is applied, preventing the body from moving; adjusts itself up to a maximum value. |
| Limiting Friction | The maximum value of static friction, reached just before the body starts to move. |
| Kinetic (Dynamic) Friction | The friction that acts between two surfaces when one body is actually sliding over another; slightly less than limiting friction. |

| | |
|---|---|
| Rolling Friction | The friction that acts when one body rolls over the surface of another, such as a wheel rolling on a road; generally much smaller than sliding friction. |

Among these, static friction (up to its limiting value) is generally the largest, followed by kinetic friction, with rolling friction being the smallest. This is the reason wheels and rollers are widely used in machines and vehicles to reduce the effort needed to move heavy loads.

## 3. Laws of Limiting Friction

The behaviour of limiting friction (the maximum static friction just before a body begins to slide) has been found experimentally to follow certain definite laws, known as the laws of limiting friction:

1. The force of limiting friction always acts along the surface of contact, in a direction opposite to the direction in which the body tends to move.
2. The magnitude of limiting friction is directly proportional to the normal reaction between the two surfaces in contact.
3. The magnitude of limiting friction depends on the nature and material of the surfaces in contact (that is, how rough or smooth they are), but is independent of the apparent area of contact between the two surfaces, as long as the normal reaction remains unchanged.
4. The limiting friction is independent of the speed of relative motion between the surfaces, provided the speed is not very high.

These laws form the basis for defining the coefficient of friction, which expresses the constant of proportionality mentioned in the second law.

## 4. Coefficient of Friction

Since limiting friction (F) is directly proportional to the normal reaction (N) between two surfaces, this relationship can be written as:

- $F = \mu N$

where μ (mu) is a constant of proportionality called the coefficient of friction. Rearranging this expression gives the definition of the coefficient of friction as the ratio of the limiting friction to the normal reaction between the two surfaces:

- $\mu = F / N$

Since the coefficient of friction is defined as the ratio of two forces of the same kind (both measured in newtons), it is a dimensionless quantity and has no units. Its value depends only on the nature and roughness of the two surfaces in contact, and typically lies between 0 and 1 for most common surface combinations, although it can occasionally exceed 1 for certain rough material pairs.

## 5. Reducing Friction and Its Engineering Applications

Although friction is essential in certain situations, in most machines it leads to unwanted wear of moving parts, generation of heat, and loss of useful energy. Engineers therefore use several methods to reduce friction between moving machine components:

| Method | Explanation / Engineering Application |
|---|---|
| Polishing and smoothing surfaces | Reduces surface irregularities, lowering friction between contacting surfaces, as used in machine slideways and bearing surfaces. |
| Lubrication | Applying oil or grease between moving parts, such as in engines and machine bearings, reduces direct contact and friction. |
| Use of ball bearings and roller bearings | Converts sliding friction into much smaller rolling friction, widely used in wheels, axles, and rotating machine shafts. |
| Streamlining | Shaping vehicles, aircraft, and ships to reduce fluid friction (air or water resistance) during motion. |
| Use of grease and graphite powder | Provides a thin low-friction film between surfaces in machine parts where liquid lubricants are unsuitable. |

By reducing friction using these methods, machines run more smoothly, generate less heat, experience less wear and tear, and consume less energy, resulting in higher mechanical efficiency and a longer working life for moving parts.

## 6. Work Done in Moving an Object on a Rough Inclined Plane

Consider a body of weight $mg$ placed on a rough inclined plane that makes an angle $\theta$ with the horizontal, with the coefficient of friction between the body and the plane being $\mu$. When the body is pulled up the incline through a distance $s$ along the surface of the plane, work must be done against two opposing effects: the component of gravity acting down the incline, and the frictional force acting down the incline (opposing the upward motion).

The weight mg of the body can be resolved into two components relative to the inclined surface:

- A component mg $\sin\theta$ acting down the incline, parallel to the surface.
- A component mg $\cos\theta$ acting perpendicular to the incline, balanced by the normal reaction N of the plane (so $N = mg\cos\theta$).

The frictional force acting on the body, opposing its upward motion along the incline, is therefore:

- $f = \mu N = \mu mg\cos\theta$

As the body moves up the incline through a distance s, the total work done by the pulling force must overcome both the component of gravity along the incline and the frictional force. The work done against gravity and the work done against friction are therefore:

- Work done against gravity = $mg\sin\theta \times s$
- Work done against friction = $\mu mg\cos\theta \times s$

Hence, the total work done in moving the body up the rough inclined plane through a distance s along the incline is the sum of these two quantities:

- $W = mg\,s(\sin\theta + \mu\cos\theta)$

This shows that the presence of friction always increases the total work required to move a body up an incline, compared to a smooth (frictionless) incline, where the work done would simply be $mg\,s\sin\theta$ (equal to mgh, the work done against gravity alone, where $h = s\sin\theta$ is the height gained).

Similarly, if the body slides down the incline, friction opposes the downward motion and acts up the incline, so the net work obtained (or the effective driving force) is reduced by the frictional term, giving the work associated with motion down the incline as $mg\,s(\sin\theta - \mu\cos\theta)$, provided $\sin\theta > \mu\cos\theta$ so that the body actually slides down.

***Worked Example:***

A body of mass 10 kg is pulled up a rough inclined plane of angle 30° through a distance of 5 m along the incline. The coefficient of friction between the body and the plane is 0.2. Calculate the total work done. (Take $g = 10\ m/s^2$)

Solution: Using $W = mg\,s(\sin\theta + \mu\cos\theta)$: $mg = 10 \times 10 = 100$ N. $\sin 30° = 0.5$ and $\cos 30° = 0.866$. $W = 100 \times 5 \times (0.5 + 0.2 \times 0.866) = 500 \times (0.5 + 0.173) = 500 \times 0.673 = 336.5$ J. Therefore, the total work done in pulling the body up the incline is approximately 336.5 joules.

## 7. Multiple Choice Questions (MCQs)

Answer the following questions by selecting the most appropriate option.

**1. Friction is a force that acts:**

A) In the direction of motion
B) Opposite to the direction of relative motion or tendency of motion
C) Perpendicular to the surface of contact
D) In no particular direction

**2. The maximum value of static friction is called:**

A) Kinetic friction
B) Rolling friction
C) Limiting friction
D) Fluid friction

**3. Which type of friction is generally the smallest in magnitude?**

A) Static friction
B) Limiting friction
C) Kinetic friction
D) Rolling friction

**4. According to the laws of limiting friction, the limiting friction is:**

A) Independent of the normal reaction
B) Directly proportional to the normal reaction between the surfaces
C) Inversely proportional to the normal reaction
D) Equal to the applied force always

**5. The coefficient of friction is defined as the ratio of:**

A) Applied force to normal reaction
B) Limiting friction to normal reaction
C) Normal reaction to limiting friction
D) Weight to applied force

**6. The coefficient of friction is:**

A) A vector quantity with units
B) A dimensionless quantity with no units
C) Always greater than 1
D) Measured in newtons

**7. According to the laws of limiting friction, limiting friction is independent of:**

A) The nature of the surfaces in contact
B) The normal reaction
C) The apparent area of contact between the surfaces
D) None of the above

**8. Which of the following reduces friction by converting sliding friction into rolling friction?**

A) Lubricating oil
B) Ball bearings
C) Polishing
D) Streamlining

**9. Streamlining of vehicles is done mainly to reduce:**

A) Rolling friction
B) Static friction
C) Fluid (air) friction
D) Limiting friction

**10. The work done against friction while moving a body up a rough inclined plane depends on:**

A) Only the weight of the body
B) The coefficient of friction and the normal reaction only
C) The frictional force and the distance moved along the incline
D) The angle of inclination only

**11. On a rough inclined plane, the normal reaction on a body of weight mg is given by:**

A) $mg$
B) $mg \sin\theta$
C) $mg \cos\theta$
D) $mg \tan\theta$

**12. The frictional force on a body of weight mg placed on a rough incline (angle θ, coefficient μ) is given by:**

A) $\mu mg$
B) $\mu mg \sin\theta$
C) $\mu mg \cos\theta$
D) $mg / \mu$

**13. Lubrication reduces friction mainly by:**

A) Increasing the normal reaction between surfaces
B) Introducing a thin film between surfaces that reduces direct solid-to-solid contact
C) Increasing the roughness of the surfaces
D) Increasing the coefficient of friction

**14. Friction is essential and useful in which of the following situations?**

A) Walking on the ground
B) Sliding of machine parts
C) Motion of pistons in a cylinder
D) Motion of a satellite in orbit

**15. The total work done in moving a body up a rough inclined plane is equal to:**

A) Work done against gravity only
B) Work done against friction only
C) The sum of work done against gravity and work done against friction
D) The difference between work done against gravity and friction

### Answer Key

1. B) Opposite to the direction of relative motion or tendency of motion | 2. C) Limiting friction | 3. D) Rolling friction | 4. B) Directly proportional to the normal reaction between the surfaces | 5. B) Limiting friction to normal reaction | 6. B) A dimensionless quantity with no units | 7. C) The apparent area of contact between the surfaces | 8. B) Ball bearings | 9. C) Fluid (air) friction | 10. C) The frictional force and the distance moved along the incline | 11. C) mg $\cos\theta$ | 12. C) $\mu$ mg $\cos\theta$ | 13. B) Introducing a thin film between surfaces that reduces direct solid-to-solid contact | 14. A) Walking on the ground | 15. C) The sum of work done against gravity and work done against friction

## 8. Broad / Long Answer and Numerical Questions

1. Define friction. Explain why friction is considered both a necessary and an undesirable force in daily life and engineering, with suitable examples of each.

2. Explain the different types of friction — static, limiting, kinetic, and rolling — with suitable examples of each.

3. State the laws of limiting friction.

4. Define the coefficient of friction. Explain its physical significance and state why it has no units.

5. Explain any four methods used to reduce friction in machines, along with their engineering applications.

6. Explain the role of lubrication in reducing friction in machine parts, and state why ball bearings are preferred over plain sliding bearings in rotating shafts.

7. Derive an expression for the work done in moving a body up a rough inclined plane, considering both the component of gravity and the frictional force acting on it.

8. Explain why the work done in pulling a body up a rough inclined plane is greater than the work done on a smooth (frictionless) inclined plane of the same height.

9. A body of mass 10 kg is pulled up a rough inclined plane of angle 30° through a distance of 5 m along the incline. If the coefficient of friction between the body and the plane is 0.2, calculate the total work done against gravity and friction. (Take $g = 10\ m/s^2$)

10. A block of mass 5 kg is placed on a rough horizontal surface where the coefficient of friction is 0.4. Calculate the limiting friction acting on the block. (Take $g = 10\ m/s^2$)