Chapter 7

Friction

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INTRODUCTION TO FRICTION : KINETIC FRICTION

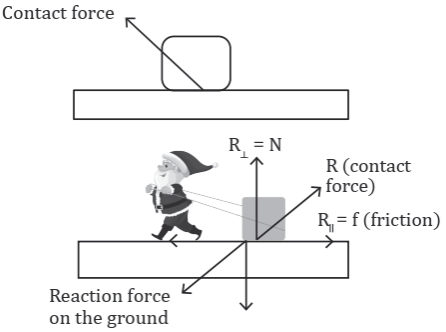
Friction is a force that arises between two surfaces in contact, acting to resist their relative motion.

Friction can be comprehended from two distinct perspectives: the macroscopic viewpoint and the microscopic viewpoint.

Macroscopic view

On a macroscopic scale, when two bodies are in contact, the particles from each body apply electromagnetic force to those of the other body. Consequently, each body applies a contact force to the other, which can manifest in any direction.

Friction is the portion of the contact force that aligns parallel to the surface in contact, while the normal reaction represents the perpendicular component of the contact force.



Microscopic view

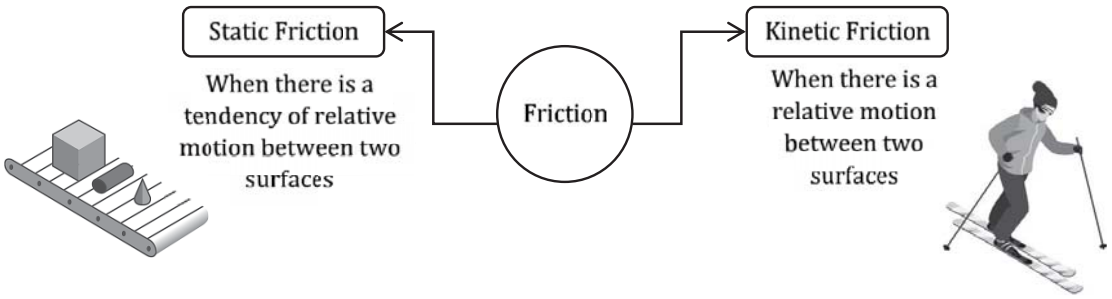
At a microscopic level, all surfaces exhibit irregularities, including projections and depressions, which lead to friction through two distinct mechanisms.

(a) **Interlocking:**

Microscopic projections on one surface interlock with depressions on another surface, thereby impeding their relative motion.

(b) **Cold welding:**

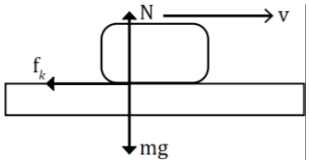
When two surfaces make contact, only a limited number of points come into direct contact with each other, resulting in a decrease in the effective contact area. This reduction in contact area leads to an increase in resultant pressure. Consequently, high-pressure bonds form at these contact points, resisting the relative motion and causing friction.



Kinetic Friction

Kinetic friction occurs between surfaces in contact solely when there is relative motion between them.

The strength of kinetic friction correlates directly with the normal reaction force applied to the contact surface.



Kinetic friction force (f_k) is directly proportional to normal reaction force (N).

$$f_k \propto N$$

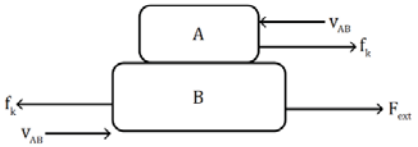
$$f_k = \mu N$$

Here, μ is the proportionality constant known as coefficient of kinetic friction.

Note: As the normal force acts in opposition to the net force perpendicular to the surface of contact, it does not always equate to the weight of the object. Therefore, we cannot assert that kinetic friction directly correlates with the weight of the object.

Direction of Kinetic Friction

Kinetic friction acts against the motion between objects. Consequently, for an object, the direction of kinetic friction opposes its relative velocity concerning the other object it's in contact with.



In this diagram, block A is sliding backward in relation to B, causing kinetic friction on A to act in the forward direction. The kinetic friction on B mirrors that of A in magnitude but opposes it in direction. Consequently, kinetic friction on B is acting in the backward direction.

Put differently, the direction of kinetic friction acting on body A opposes the relative velocity of A in relation to B.

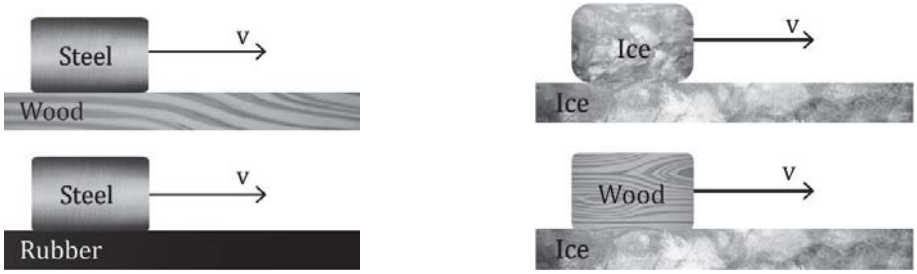
Note: Kinetic friction consistently opposes relative motion and may not align directly with the applied force. For instance, in the depicted scenario, the kinetic friction on block A is parallel to the external force applied.

When two bodies are in relative motion, the kinetic frictional force acting on one body equals and opposes the kinetic frictional force acting on the other body.

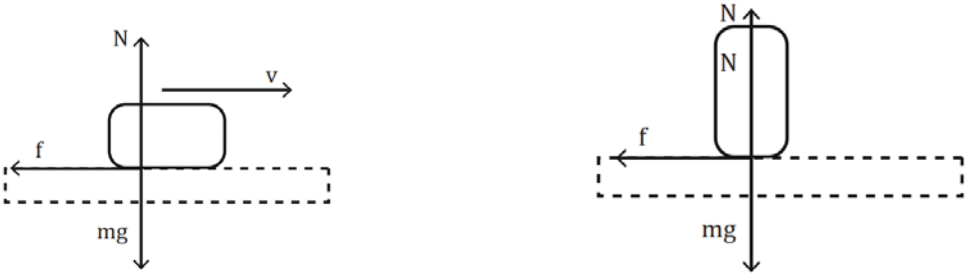
Properties of Coefficient of Kinetic Friction (μ_k)

The coefficient of kinetic friction (μk) varies based on the nature of the surfaces in contact. It isn't defined for an individual material but rather for a pair of material surfaces in contact.

For instance, the coefficient of kinetic friction varies among the depicted pairs.



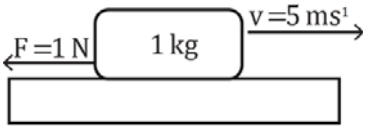
The coefficient of kinetic friction remains unaffected by the surface area in contact.
For instance, whether a body rests on its larger or smaller face, the frictional force remains constant.



The coefficient of kinetic friction remains unaffected by the relative speed of the surfaces in contact.

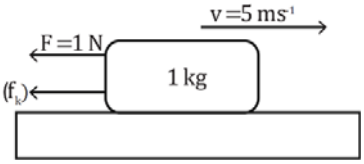
Note: The magnitude of kinetic friction relies solely on the normal reaction force and the coefficient of kinetic friction, both of which are independent of relative velocity.
The direction of kinetic friction consistently opposes the direction of relative velocity.

Ex. Find the direction of kinetic frictional force at the given instant.

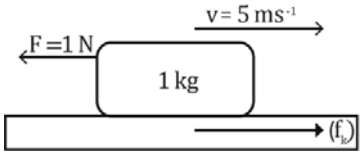


(a) On the block, exerted by the ground
(b) On the ground, exerted by the block

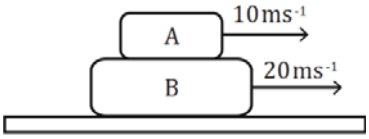
Sol. **(a)** The kinetic friction acting on the block, generated by the ground, opposes the relative velocity and remains unaffected by the applied force. Therefore, the kinetic friction on the block operates in the leftward direction.



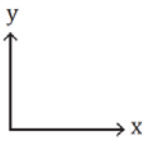
(b) The kinetic friction experienced by the ground due to the block is equal in magnitude and opposite in direction to the kinetic friction experienced by the block. Consequently, the kinetic friction on the ground operates in the rightward direction.



Ex. All surfaces shown are rough. Draw the kinetic friction force on A and B.

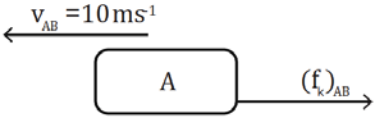


Sol. Block A is in contact with only block B. Hence, there is only one kinetic frictional force acting on block A.
While block B is in contact with block A and the ground. Hence, there are two kinetic frictional forces acting on block B.



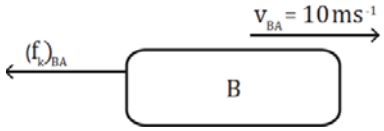
Direction of kinetic friction force on A exerted by B
Kinetic friction acts opposite to the relative velocity of the object with respect to the other object in contact.
To find relative velocity of A with respect to B,

$$\vec{V}_{AB} = \vec{V}_A - \vec{V}_B$$
$$= 10\hat{\imath} - 20\hat{\imath} = -10\hat{\imath}\,ms^{-1}$$



Relative velocity of A with respect to B is in the negative x direction. So, the direction of kinetic friction exerted on A by B is in the positive x direction

Direction of kinetic friction force on B exerted by A

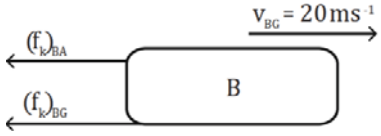


To find relative velocity of B with respect to A, take A as the frame of reference.

$$\vec{v}_{BA} = \vec{v}_B - \vec{v}_A$$
$$= 20\hat{\imath} - 10\hat{\imath} = 10\hat{\imath} ms^{-1}$$

Relative velocity of B with respect to A is in positive x direction. So, the kinetic friction force on B is acting in negative x direction.

Kinetic friction on B exerted by ground

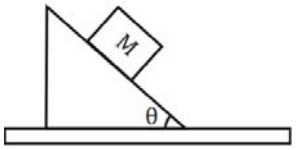


To find relative velocity of B with respect to the ground, take ground as the frame of reference.

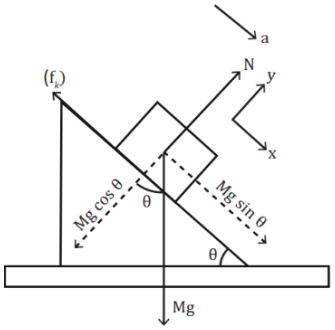
$$\vec{v}_{BG} = \vec{v}_B - \vec{v}_G$$
$$= 20\hat{\imath} - 0\hat{\imath} = 20\hat{\imath} ms^{-1}$$

Relative velocity of B with respect to the ground is in positive x direction. So, the direction of kinetic friction on B exerted by ground is in negative x direction.

Ex. A block of mass M is sliding down on a fixed wedge that is making an angle θ with the horizontal. The coefficient of friction between the block and the wedge is μ. Find the magnitude and direction of the friction on the block and its acceleration.



Sol. In the question, it is given that the block is sliding down. So, there will be a kinetic friction acting along the inclined plane in the upward direction.



In y-direction,

$N = Mg\cos\theta$

Kinetic friction, $f_k = \mu N = \mu(Mg\cos\theta)$ $\vec{f}_k = -(Mg\cos\theta)\hat{\imath}$

In x-direction,

$$Mg\sin\theta - f_k = Ma$$
$$Mg\sin\theta - \mu(Mg\cos\theta) = Ma$$

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

$$\vec{a} = g(\sin\theta - \mu\cos\theta)\hat{\imath}$$