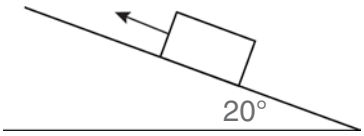
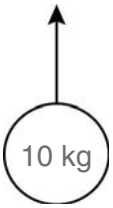
9. A crate is pulled uphill against friction.

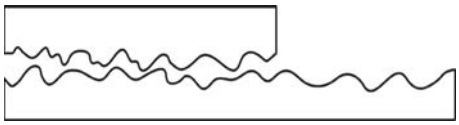


10. An object is accelerated upwards by a rope in a vacuum.



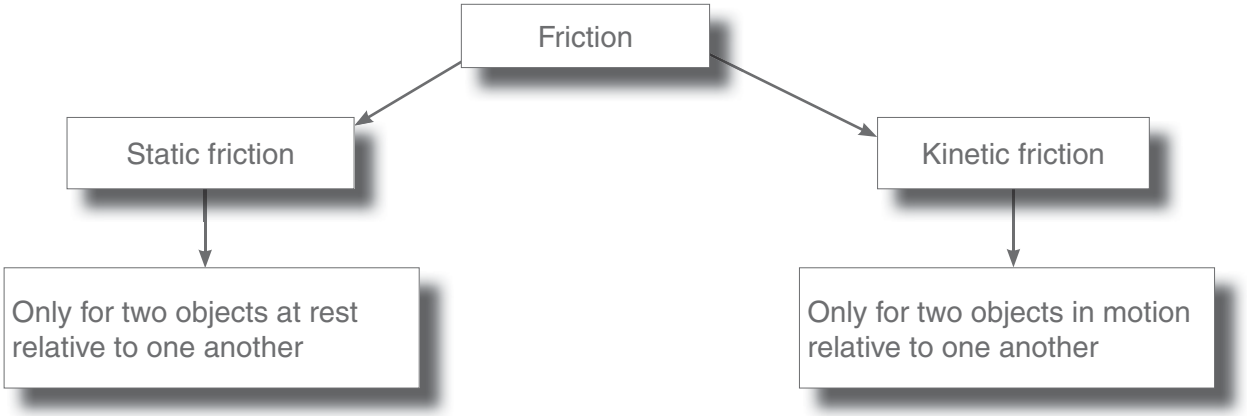
1.6 Friction force

Friction is a contact force.
Friction occurs when two objects are in close contact and attempt to move across each other.
A surface might seem smooth, but microscopically it has uneven particles.



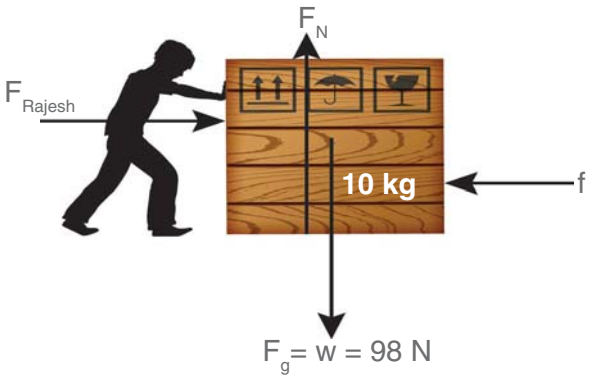
The surfaces of solids are generally relatively rough.
The uneven sections of the rough surfaces of two objects get caught on each other when sliding (or trying to slide) against each other.
Friction occurs, which opposes the motion of two surfaces against each other.

Quick facts
Frictional forces act parallel to the plane of motion, but are always in the opposite direction to the motion.



Examples

Rajesh pushes a crate across a rough surface, as indicated in the diagram. The applied force is labelled F_{Rajesh} and the friction is labelled f. At first, his force is not large enough to overcome the friction, so he keeps increasing it.



Study the following table to understand how the friction varies:

Magnitude of applied force F_{Rajesh} (N)	Crate	Magnitude of friction force f (N)	Type of friction force
40	At rest.	40	Static
60	At rest.	60	Static
80	At the point of starting to move.	80	Static
82	Accelerates to the right.	60	Kinetic
85	Accelerates to the right.	60	Kinetic

Initially, the static frictional force is equal to the applied force and the crate is not moving.
As the applied force increases, the static friction increases equally, to resist the movement.
From the table it is clear that the static friction force reaches a maximum magnitude of 80 N.
When Rajesh applies a force larger than the maximum frictional force, the crate starts to move and accelerate.
The kinetic friction is now smaller than the maximum value of the static friction.
As soon as the crate is in motion, the frictional force is smaller.

1.6.1 Which factors influence the magnitude (size) of the frictional force?

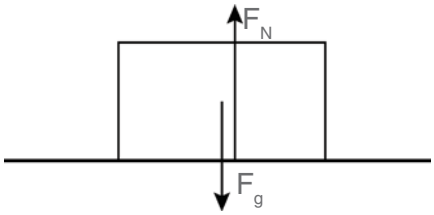
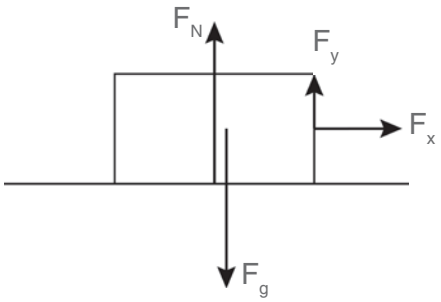
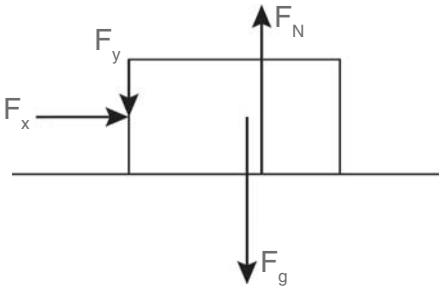
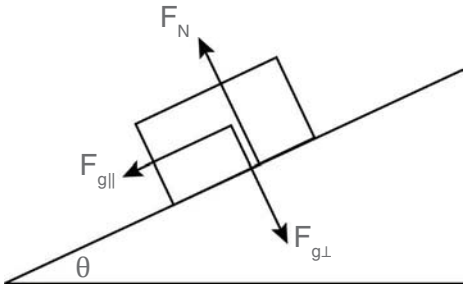
Factors that influence friction:
- normal force;
- surface type.

1. The normal force

The larger the forces that the two surfaces exert on each other perpendicular to the surface, the larger the friction.

The normal is an indication of this. To calculate friction, we need to know what the normal is. It is often equal to the weight, but not always.

How to determine the normal force F_N in various situations.

1	An object on a horizontal plane; an object resting on a surface has a normal equal to the gravitational force, but in the opposite direction.		$F_N = F_g = w$
2	An object on a horizontal plane; object pulled by a force at an angle to the horizontal. 		Pulling force replaced by its components. $F_x = F\cos\theta$ $F_y = F\sin\theta$ Then: $F_N = F_g - F_y$
3	An object on a horizontal plane; object pushed by a force at an angle to the horizontal. 		Pushing force replaced by its components. $F_x = F\cos\theta$ $F_y = F\sin\theta$ Then: $F_N = F_g + F_y$
4	An object on a slope; object is likely to slide down the slope due to the parallel component of the weight.		F_g replaced by its components: $F_{g\parallel} = F_g\sin\theta$ $F_{g\perp} = F_g\cos\theta$ Then: $F_N = F_g\cos\theta$

Quick facts

Scientists have found that the magnitude of the friction is directly proportional to the magnitude of the normal force on that surface. Mathematically, the ratio is written as $f \propto F_N$.

2. Types of surfaces

The material used in the manufacturing of a surface, plays an important role.
Example:

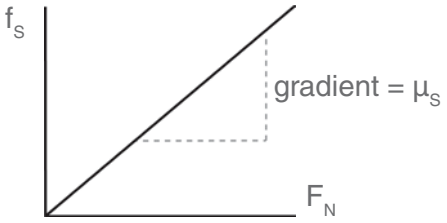
- Smooth tiles are very slippery.
- Slightly melted ice on an ice skating rink makes it very easy to glide over, but a rubber mat next to the rink makes gliding almost impossible.

The rougher the surfaces, the greater the friction between the surfaces.
The extent to which the two surfaces will affect one another is represented by a number called the coefficient of friction (μ).

Quick facts

μ (pronounced "mu") is the symbol for the coefficient of friction.

1.6.2 Coefficient of friction



- Symbol: μ
- No unit, as it is a factor of roughness.
- Every surface pair has two coefficients of friction:
  - the coefficient of static friction: μ_S;
  - the coefficient of kinetic friction: μ_K.
- The proportionality constant of the relationship $f \propto F_N$ is known as the coefficient of friction.
- The maximum coefficient of static friction is normally larger than the coefficient of kinetic friction.
- Therefore: $\mu_S > \mu_K$
- The smaller the value of μ, the less resistance is offered by a surface.
- The value is usually less than 1.

1.6.3 How to reduce friction

- Lubricate the surfaces with oil, grease or finely powdered graphite.
- Wet the surfaces with water.

The following are examples of coefficients of static and kinetic friction for different contact surfaces. (Do not try to memorise these values.)

Contact surface	μ_S	μ_K
Cast iron on cast iron	1,1	0,15
Glass on glass	0,94	0,4
Leather on oak wood	0,61	0,52
Wood on wood	0,25 – 0,5	0,2
Ice on ice	0,1	0,03