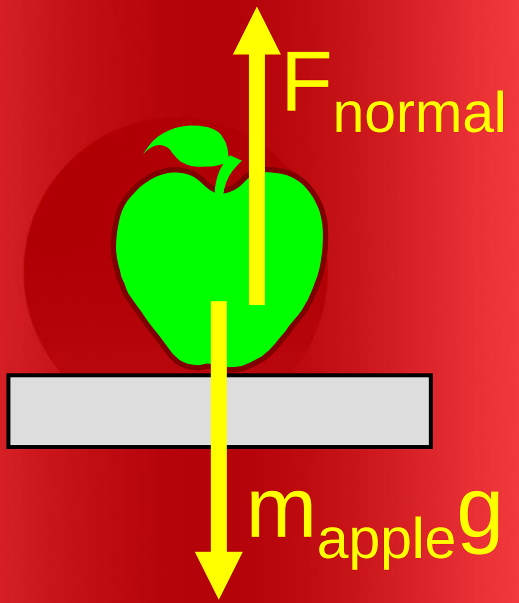
Physics

Applying Newton's Laws

EQUILIBRIUM

The state of a system when the sum of all forces acting upon it vanishes.

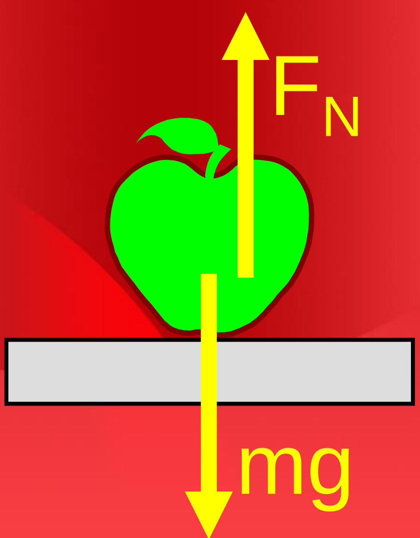


Why doesn't the apple fall through the table?

The table exerts a force which stops the apple.

This force is called the NORMAL force.

"NORMAL" means perpendicular. The NORMAL force adjusts itself to stop the object from falling through the table top.



$$\sum F = F_N - m\,g$$

$$= m\,a_y$$

$$\text{But } a_y = 0 \text{ and so } F_N = m\,g$$

A pencil that is balanced on my finger.

A plane flying at a constant velocity.

Demonstration: pellet released

Is a ball in equilibrium at the highest point?

Whether a system is in equilibrium or not can be discovered by looking at the acceleration

An aircraft of mass m has position vector that is measured to be:

$$\vec{r} = (at + bt^3)\hat{i} + (ct^2 + dt^4)\hat{j}$$

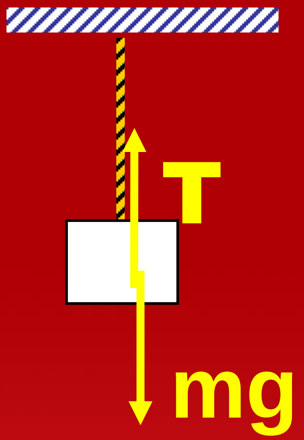
What force is acting upon it?

SOLUTION:

$$\vec{F} = m\frac{d^2x}{dt^2}\hat{i} + m\frac{d^2y}{dt^2}\hat{j}$$

$$= 6bmt\,\hat{i} + m(2c + 12dt^2)\,\hat{j}$$

Tension

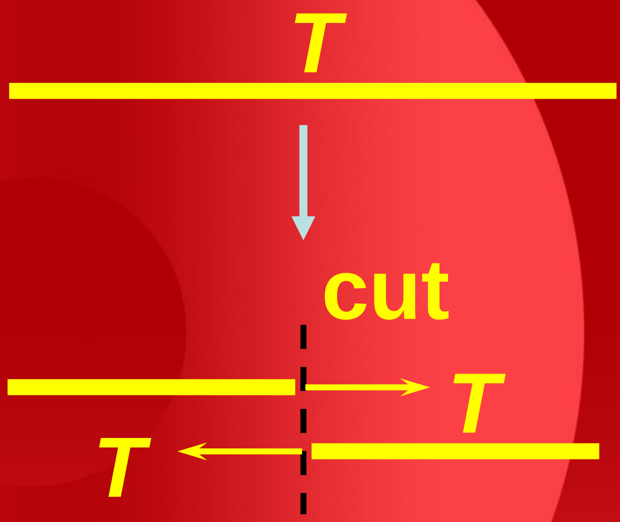


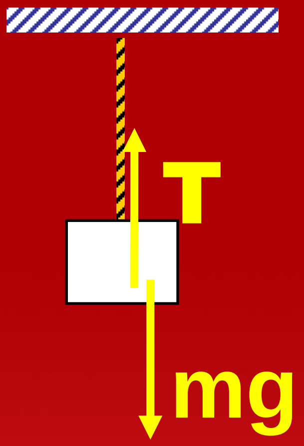
Why doesn't the box fall?

Because the rope pulls up!

The force in the rope is called TENSION.

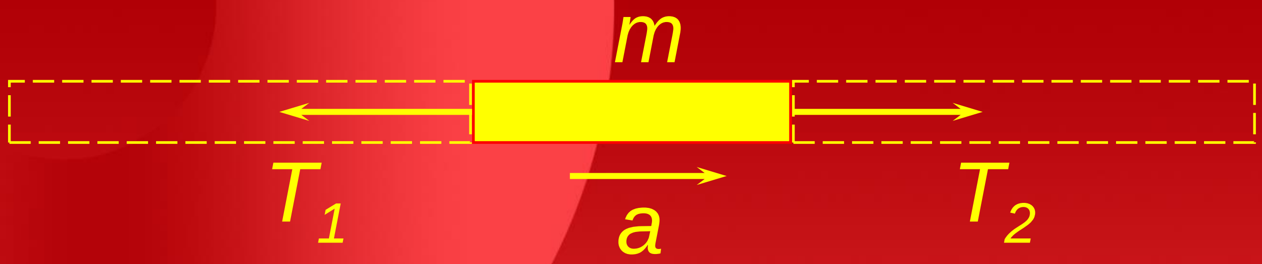
Tension (T) is the force you would feel if you cut the rope and grabbed the ends.





Ropes are useful because you can pull from a distance to change the direction of a force

Consider a horizontal segment of rope:

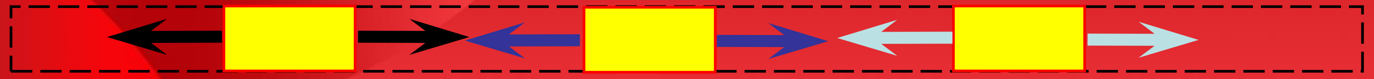


By Newton's 2nd Law:

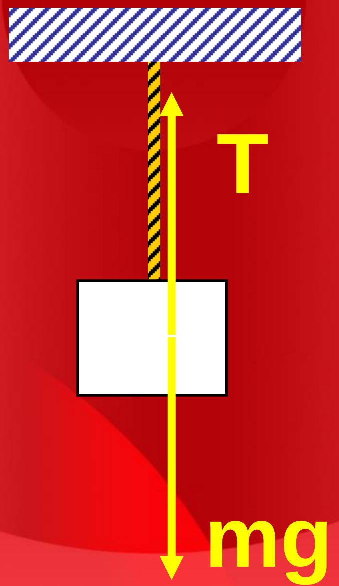
$$\Sigma F = T_2 - T_1 = m\,a$$

So if $m = 0$ (*i.e.* the rope is light) then $T_1 = T_2$

- An ideal (massless) rope has constant tension.
- Newton's 3rd Law (action-reaction) is the key !!



The direction of the force provided by a rope is along the direction of the rope



$$\Sigma F = T - mg = ma_y$$

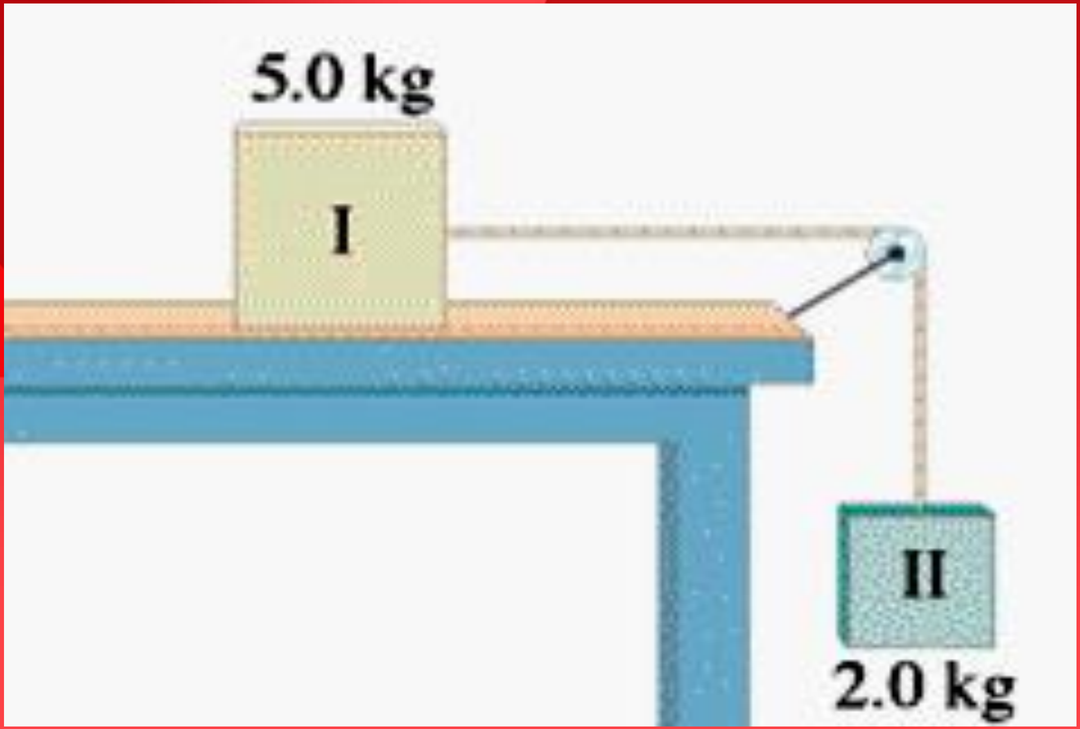
since $a_y = 0$ therefore:

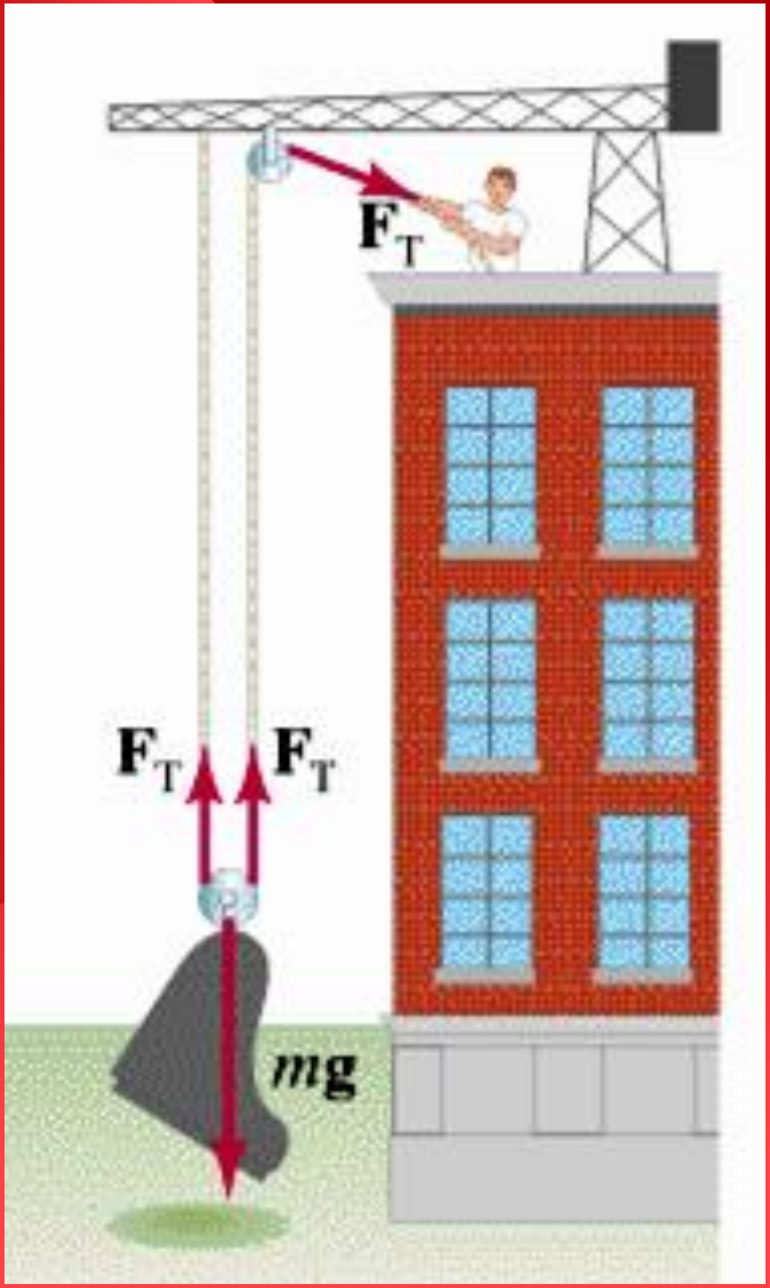
$$T - mg = 0$$

$$T = mg$$

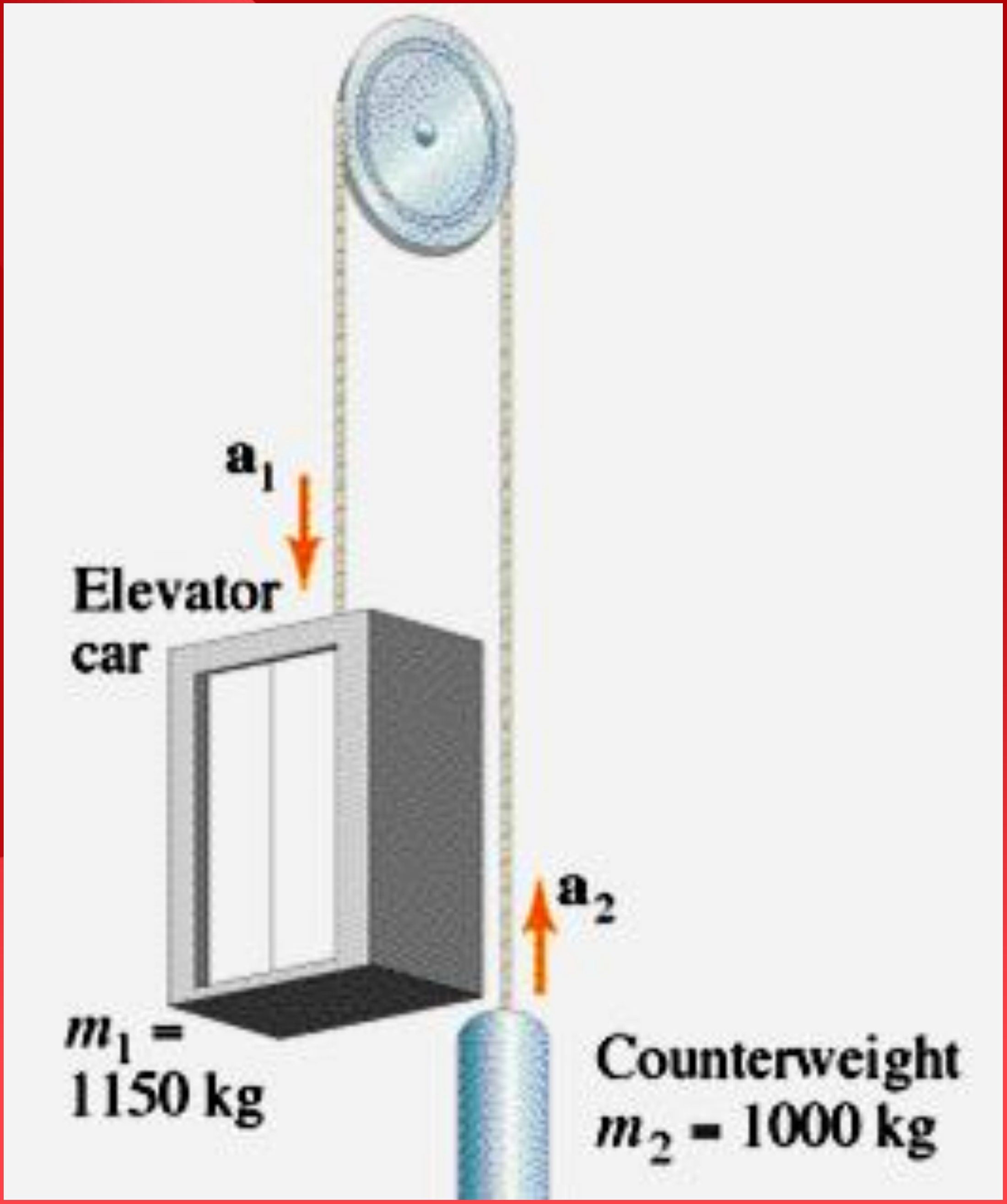
What happens if the rope is massive?

The direction of the TENSION can be changed by winding the rope around a pulley:





F_T
F_T
F_T
mg


a1
Elevator car
a2
m1 = 1150 kg
Counterweight
m2 = 1000 kg

- Tug of war animation:
- Is the tension uniform?
- Why are they wearing tennis shoes?
- What would happen with ice?
- In space?

Masses connected by strings

If m_1 is pulled by a force F then a tension T develops in the string.

$$F - T = m_1 a$$

$$T = m_2 a$$

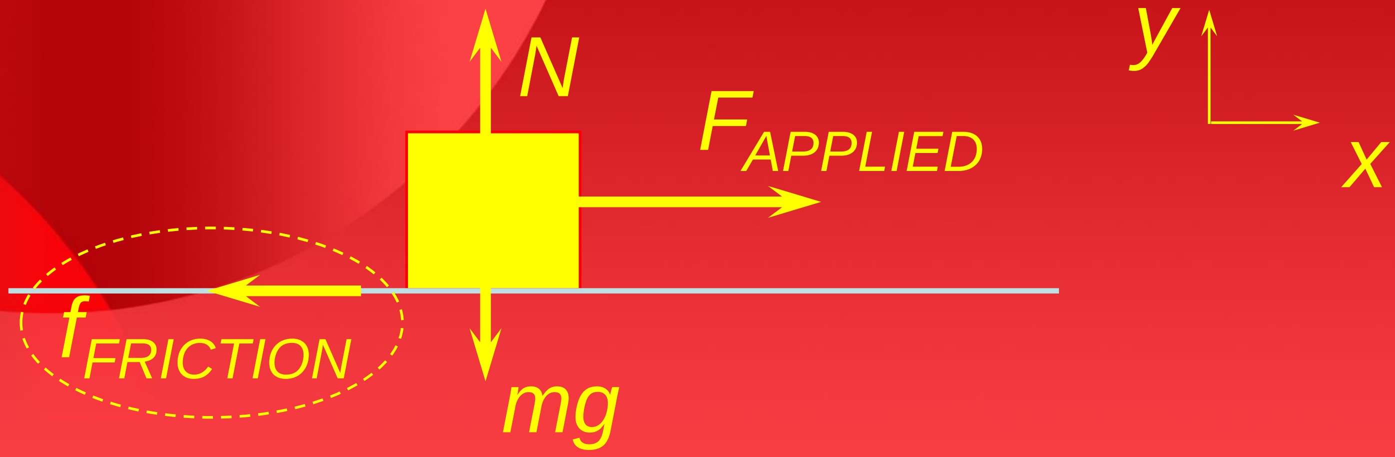
Solving these, we get

$$T = \frac{m_2 F}{m_1 + m_2} \qquad a = \frac{F}{m_1 + m_2}$$

Friction

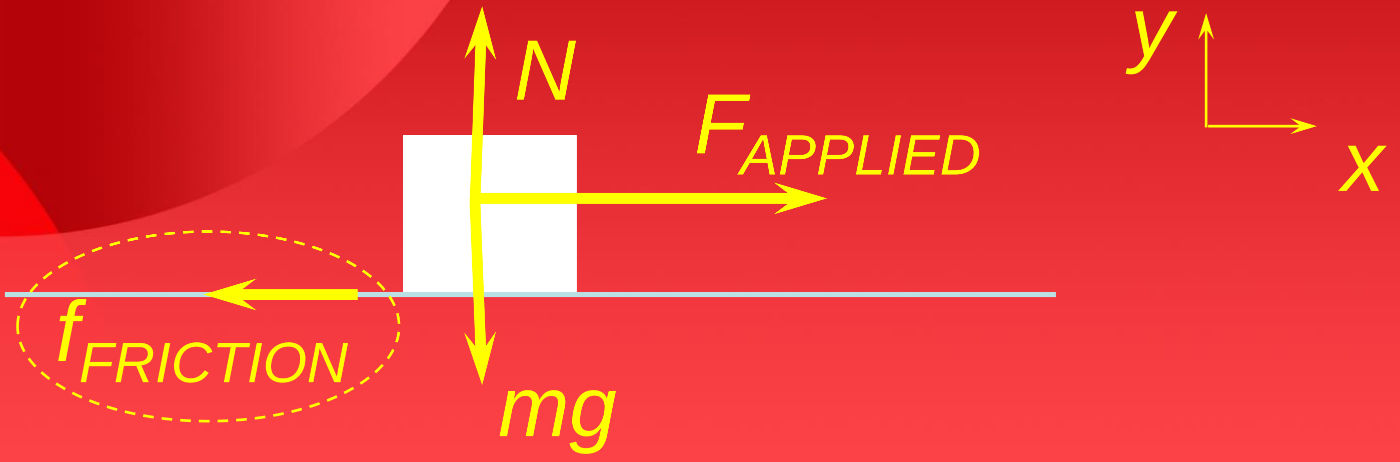
What does it do?

It opposes motion!

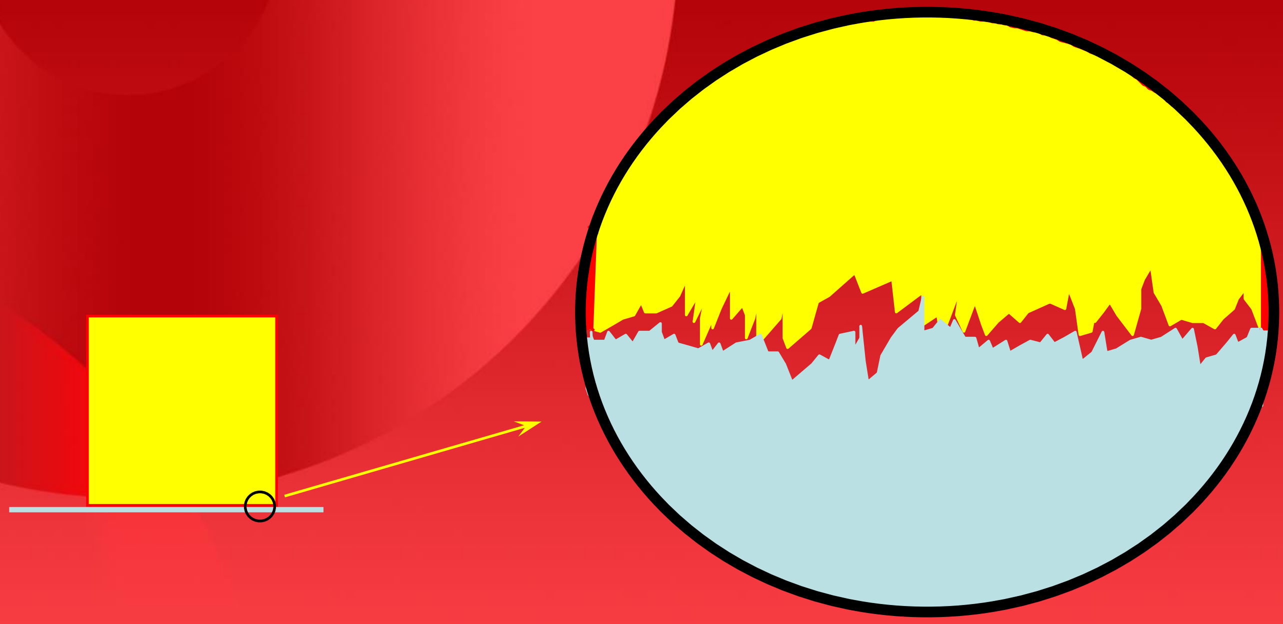


- Friction results in a force *parallel* to the surface, in a direction *opposite* to the direction of motion!

- Frictional force is perpendicular to normal force



Friction is caused by the“microscopic” interactions between the two surfaces:



Frictional force f_F is proportional to the normal force N .

- $f_F = \mu_k N = \mu_k mg$
- The constant of proportionality μ_k is called the “coefficient of kinetic friction”.
- The “heavier” something is, the greater the friction will be.

The nature of empirical law

Dynamics

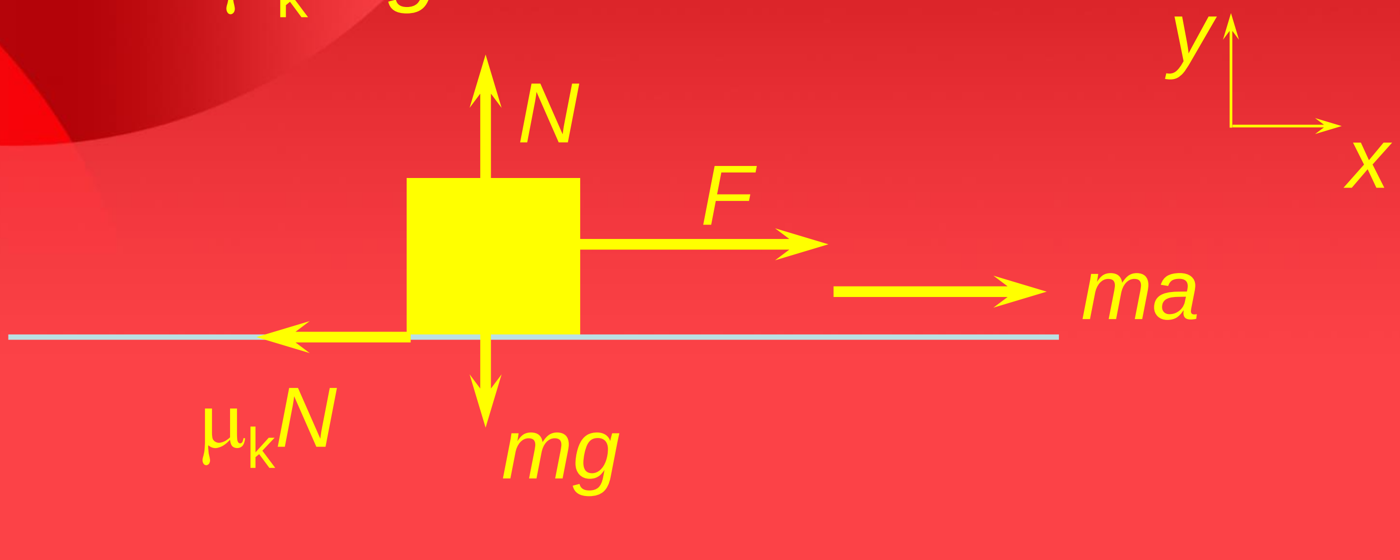
x direction: $\Sigma F_x = F - \mu_k N$

$= ma$

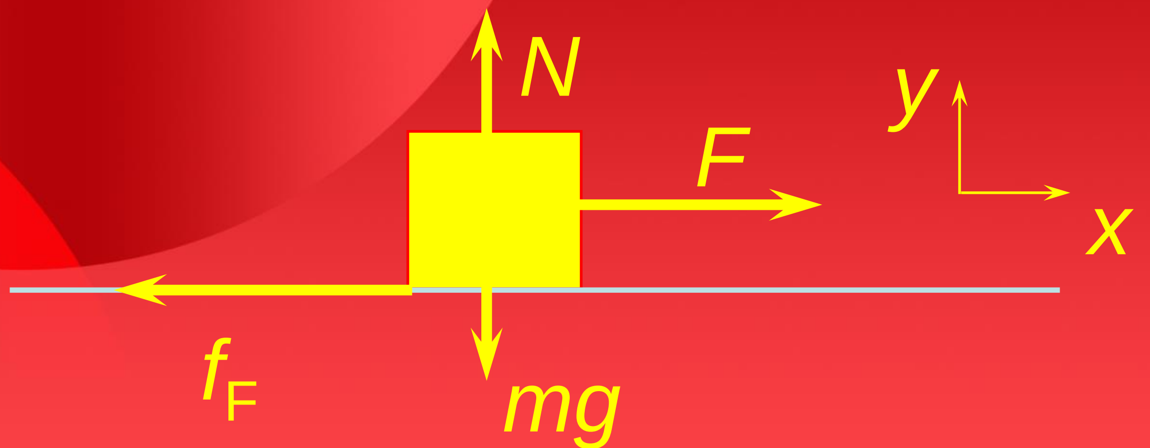
y direction:

$\Sigma F_y = N - mg = 0 \longrightarrow N = mg$

so $F - \mu_k mg = ma$

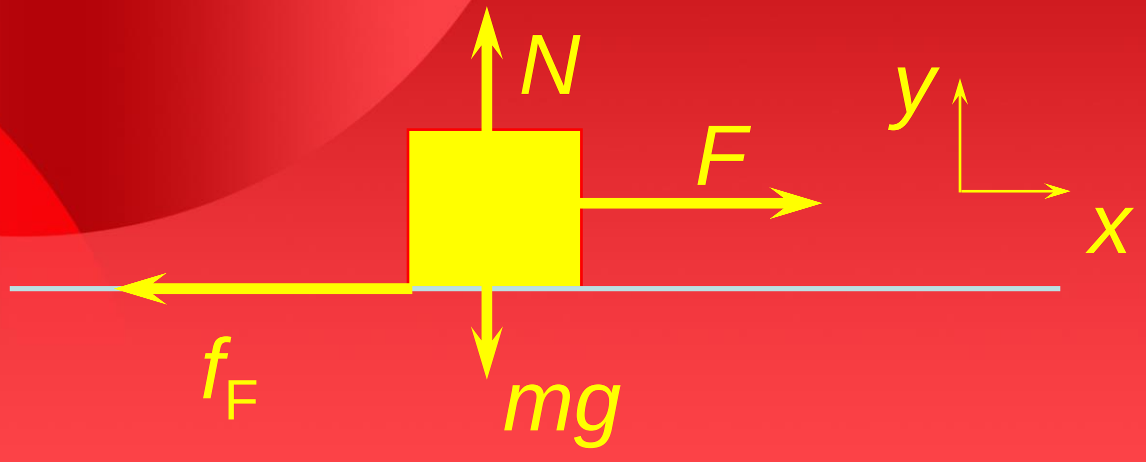


Friction acts when something moves (kinetic friction). But it also acts in un-moving "static" situations.



STATIC FRICTION

In this case, the force provided by friction depends on the forces applied on the system.

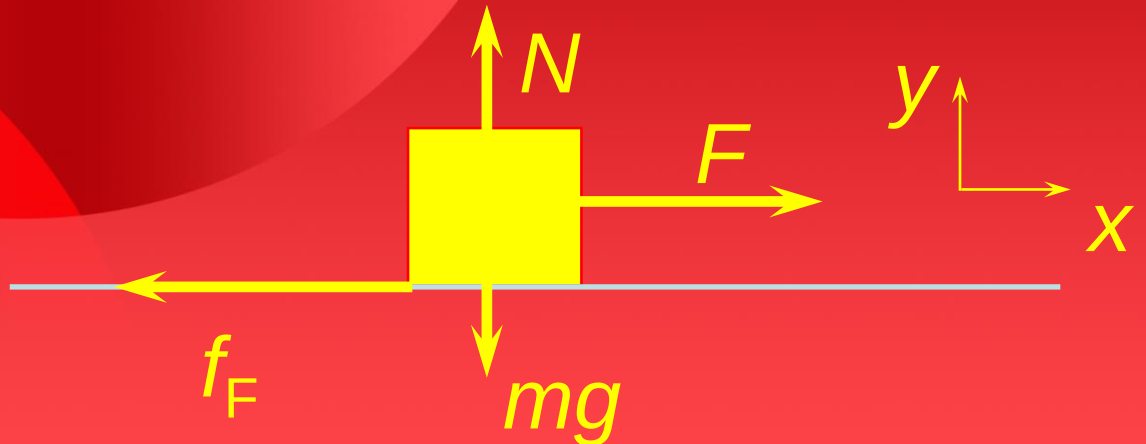


Just like in the sliding case except that

$$\boldsymbol{a_x = 0}$$

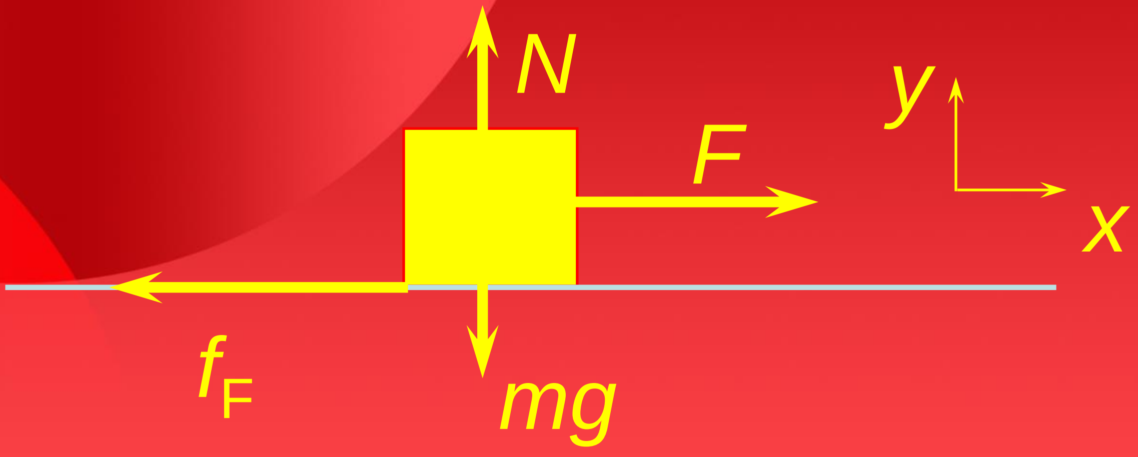
x direction: $\Sigma F_x = F - f_F = 0, \quad F = f_F$

y direction: $\Sigma F_y = N - mg = 0, \quad N = mg$



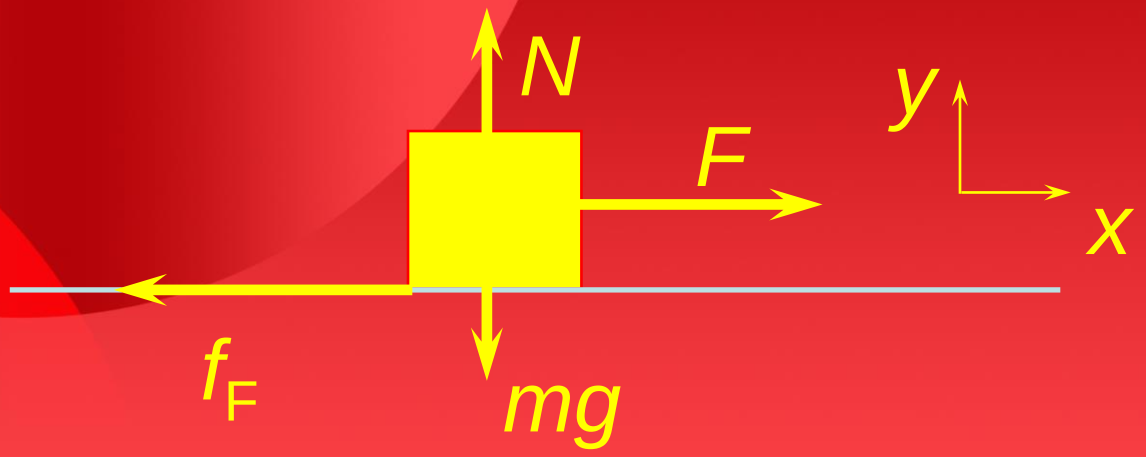
The maximum possible force that static friction can provide is $f_{MAX} = \mu_s N$

μ_s is called the "coefficient of static friction"



So $f_F \le \mu_s N$!!

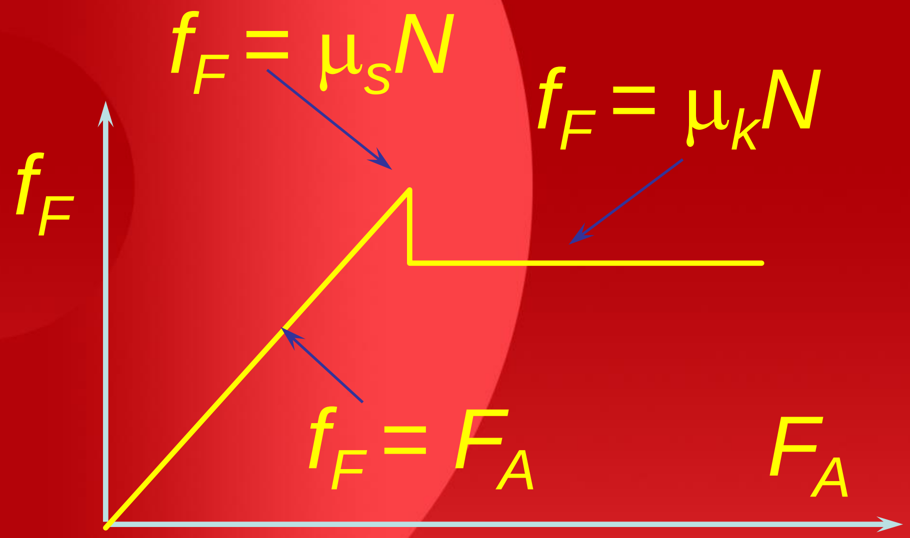
As F increases, f_F gets bigger until $f_F = \mu_s N$ and then the object starts to slide.



Since $f_F = \mu N$, the force of friction does not depend on the area of the surfaces in contact.

It is true that $\mu_s > \mu_k$ for any system.

Friction can be reduced!

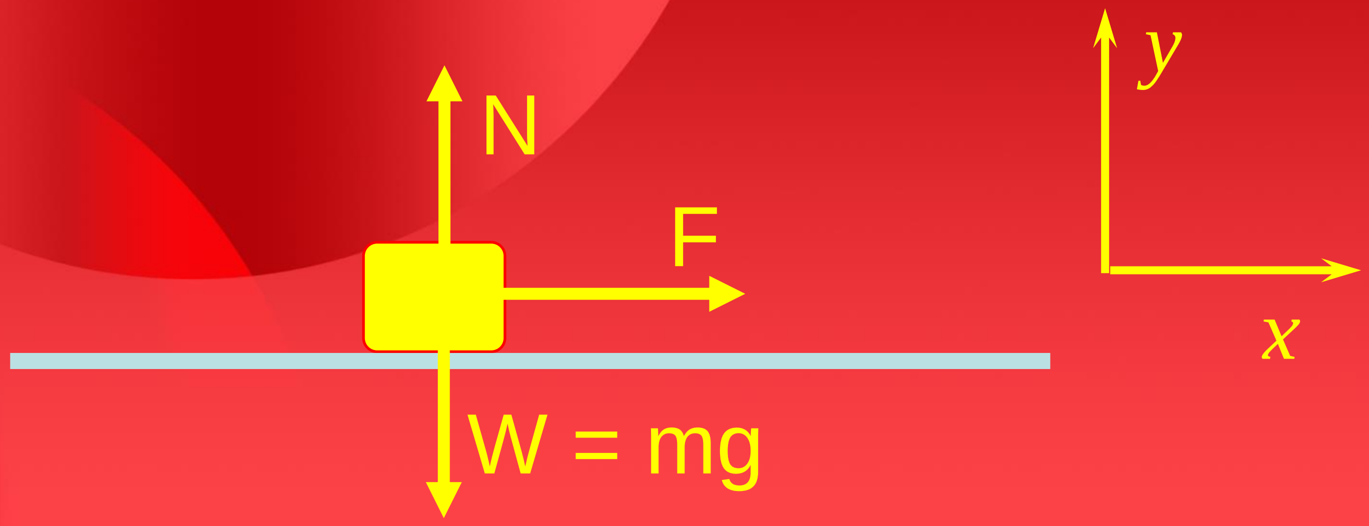


Frictional force vs. Applied force

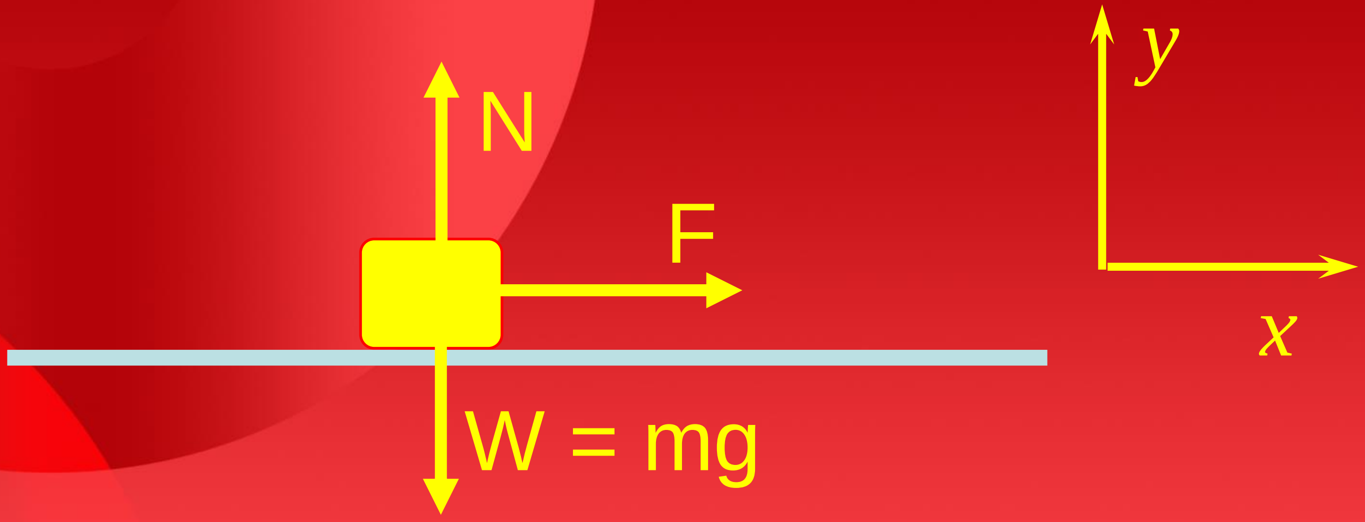
Rolling friction is less than sliding friction!!

Q: A box of mass $m = 2\ kg$ slides on a frictionless floor. A force $F_x = 10N$ pushes on it in the x direction.

- What is the acceleration of the box?
- What forces acting on the box?



Solve Newton's equations for each component. Remember the x and y components are independent!

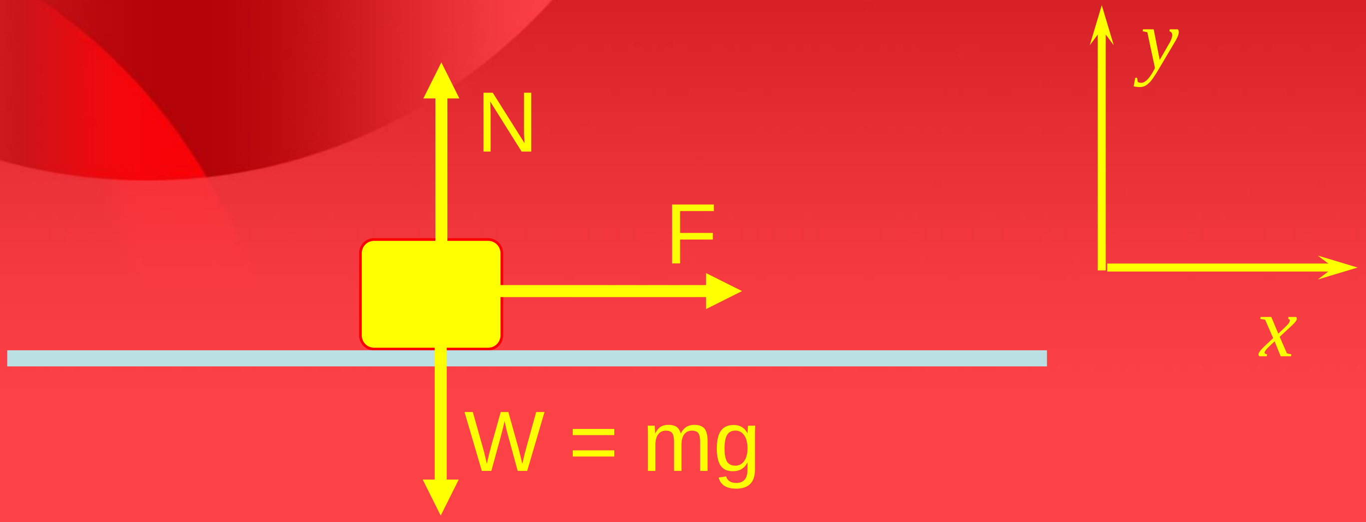


- $\Sigma F_x = F = ma_x$
- $\Sigma F_y = N - mg = ma_y$

x-direction: $a_x = F / m = 10\ N / 2\ Kg$

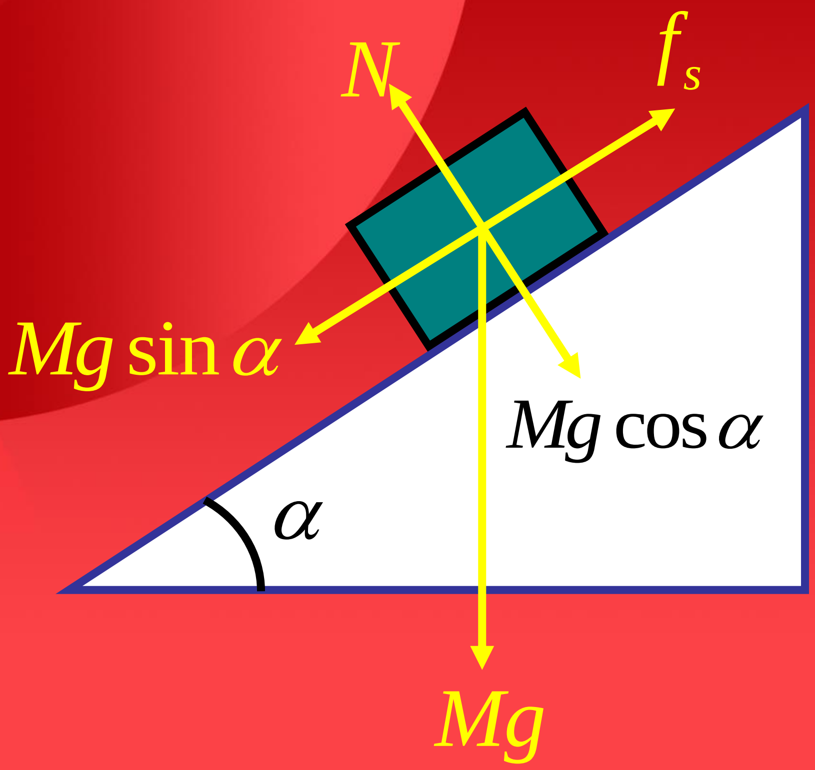
y-direction: $a_y = 0$

(no motion in y direction) thus, $N = mg$



ANGLE OF REPOSE

The angle at which a body just starts to slide down is called “angle of repose”.



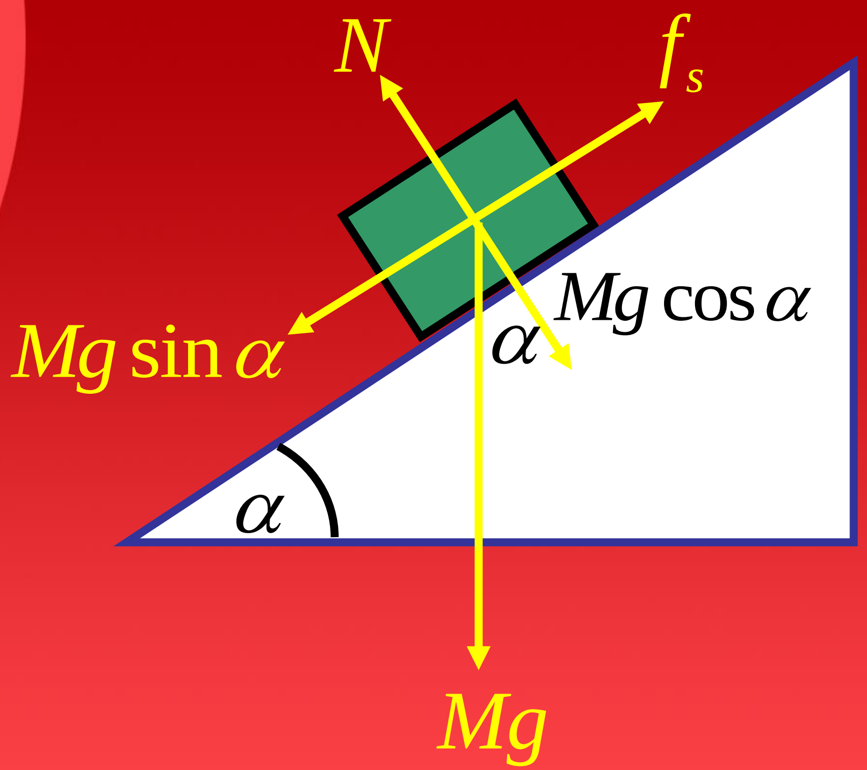
$$f_s = Mg\sin\alpha \quad \text{and} \quad N = Mg\cos\alpha$$

$$\therefore \quad \frac{f_s}{N} = \tan\alpha$$

Use $f_s = \mu N$

$$\therefore \mu = \tan\alpha$$

$$\alpha = \tan^{-1}(\mu)$$



Why do brakes work better on level ground as compared to going up or down a slope?

Why are jeeps and 4-wheel drives better?