Chapter 3

Newton's Laws of Motion

Weight

Weight = Mass x Gravity

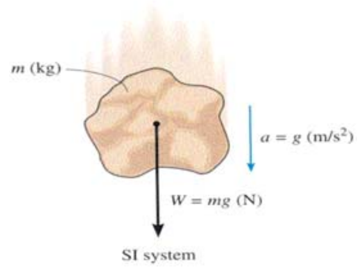
$$W = m \times g$$

The weight of an object is the gravitational force that the planet exerts on the object. The weight always acts downward, toward the center of the planet.

SI Unit of Weight: : newton (N)

- m: mass of the body (units: kg)
- g: gravitational acceleration (9.8m/s^2,

- As the mass of a body increases, its' weight increases proportionally



- Weight
  - the force of gravity on an object

$$W = mg$$

W: **weight (N)**
m: **mass (kg)**
g: **acceleration due to gravity (m/s^2)**

MASS	WEIGHT
always the same (kg)	*depends on gravity (N)*

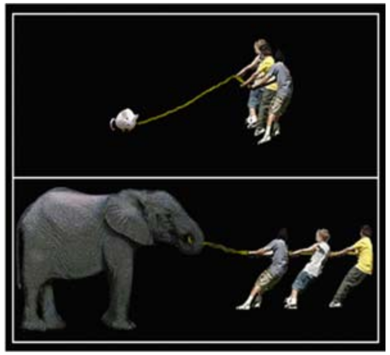
Mass …

- is a measure of how much matter there is in something -- usually measured in kilograms in science
- causes an object to have weight in a gravitational field
- a measure of the resistance of an object to changes in its motion due to a force (describes how difficult it is to get an object moving)

Note that **mass** is involved in the force of gravity! This is a separate property from that of inertia, so we give this property the name **gravitational mass**.

Mass = Inertia – an object's resistance to motion

Would it be more difficult to pull an elephant or a mouse?



- what is the weight of a 2 kg mass?

- W = F_g = mxg = 2 kg x 9.8 m/s^2
  = 19.6 N

- What is the mass of a 1000 N person?
- W = F_g = mxg
  m = F_g/g = 1000 N / 9.8 m/s^2
  =102 kg

- A girl weighs 745 N. What is his mass

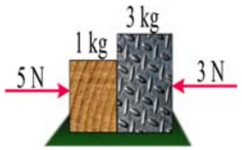
m = F ÷ g

m = (745 N) ÷ (9.8 m/s^2)

m = 76.0 kg

On a horizontal, frictionless surface, the blocks above are being acted upon by two opposing horizontal forces, as shown. What is the magnitude of the **net force** acting on the 3kg block?

A. zero
B. 2N
C. 1.5 N
D. 1N
E. More information is needed.



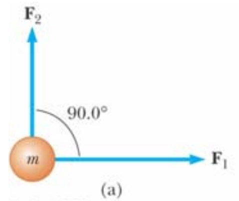
Example :

Two forces $\mathbf{F}_1$ and $\mathbf{F}_2$ act on a 5.00-kg object. If F_1 = 20.0 N and F_2 = 15.0 N, find the accelerations in (a) and (b)

(a)

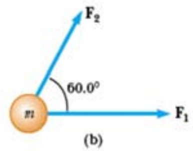
$$F = \sqrt{20^2 + 15^2} = 25N \qquad \theta = \tan^{-1}\left(\frac{15}{20}\right) = 36.9°$$

a =F/m=25/5 = 5 m / s²



(b)

$$F_x = F_{1x} + F_{2x} = 20.0 + 15.0\cos 60.0° = 27.5N$$
$$F_y = F_{1y} + F_{2y} = 0.0 + 15.0\sin 60.0° = 13.0N$$



$$F = \sqrt{27.5^2 + 13^2} = 30.4N \qquad \theta = \tan^{-1}\left(\frac{13}{27.5}\right) = 25.3°$$

a =F/m=30.4/5= 6.08 m / s²

3.3 Newton's first law

Every object continues in a state of rest , or of uniform motion in a straight line , unless it is compelled to change that state by forces acting upon it.

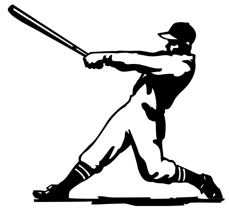
An equivalent statement of the first law is that :

An object at rest will stay at rest, and an object in motion will stay in motion at constant velocity, unless acted upon by an unbalanced force.

This, at first, does not seem obvious. Most things on earth tend to slow down and stop. However, when we consider the situation, we see that there are lots of forces tending to slow the objects down such as friction and air resistance.

Newton's First Law

- **Newton's First Law of Motion**
  - "Law of Inertia"



- **Inertia**
  - tendency of an object to resist any change in its motion
  - increases as mass increases

A railway engine pulls a wagon of mass 10 000 kg along a straight track at a steady speed. The pull force in the couplings between the engine and wagon is 1000 N.

a.What is the force opposing the motion of the wagon?
b.If the pull force is increased to 1200 N and the resistance to movement of the wagon remains constant, what would be the acceleration of the wagon?

Solution

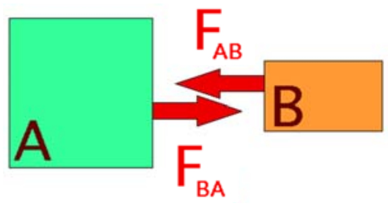
a)
When the speed is steady, by Newton's first law, the resultant force must be zero. The pull on the wagon must equal the resistance to motion. So the force resisting motion is 1000 N.
b)
The resultant force on the wagon is 1200 – 1000 = 200 N
By Equation

$$F = ma$$
$$200 = 10000a$$
$$a = 0.02 m/s^2$$

Newton's Third Law

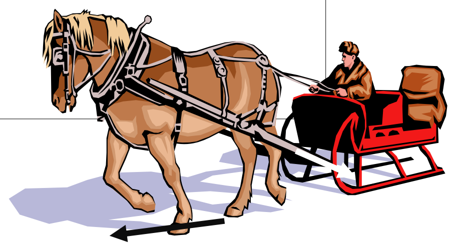
- **Newton's Third Law of Motion**
  - When one object exerts a force on a second object, the second object exerts an equal but opposite force on the first.

$$\vec{F}_{AB} = -\vec{F}_{BA}$$

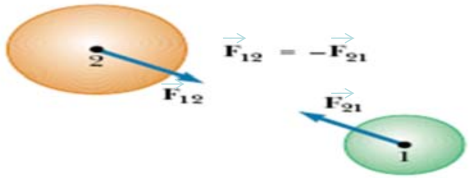


Newton's Third Law

- **Explanation:**
  - forces are equal and opposite but act on <u>different</u> objects
  - they are not "balanced forces"
  - the movement of the horse depends on the forces acting on the horse



Newton's Third Law



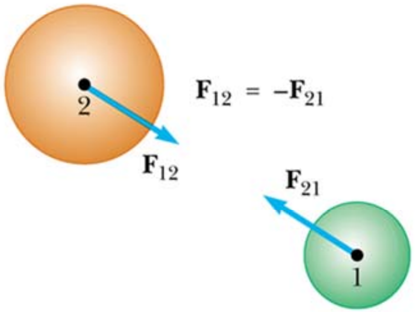
$$\vec{F}_{12} = -\vec{F}_{21}$$

Force on "2" due to "1"

- Single isolated force cannot exist
- For every action there is an equal and opposite reaction

Newton's Third Law cont.

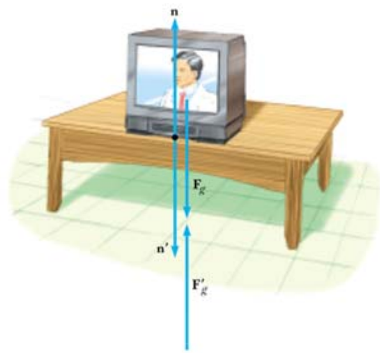
- F_{12} is *action* force F_{21} is *reaction* force
  - You can switch action <-> reaction
- Action & reaction forces act on different objects



Action-Reaction Pairs

$$\vec{n} = -\vec{n}\,'$$

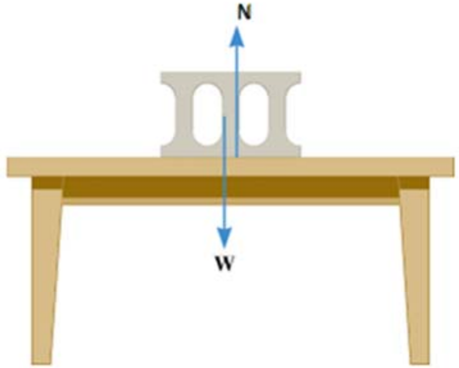
$$\vec{F}_g = -\vec{F}_g'$$



Define the *OBJECT* (free body)

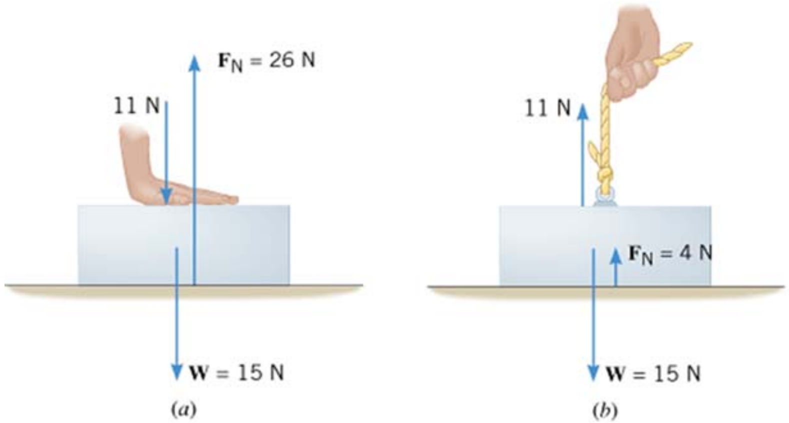
- Newton's Law uses the forces acting *ON* object
- N and F_g act on object
- n' and F_g' act on other objects

The Normal Force



The normal force **N** is one component of the force that a surface exerts on an object with which it is in contact, namely, the component that is perpendicular to the surface.

Normal Force Is Not Always Equal to the Weight



3.6 Newton's Second Law

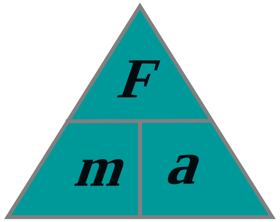
- **Newton's Second Law of Motion**
- **The force F needed to produce an acceleration a is**

$$F = ma$$

– The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

Newton's Second Law

$$a = \frac{F}{m}$$



$$F = ma$$

m: mass (kg)
a: acceleration (m/s²)

1 N = 1 kg · m/s²

- What force would be required to accelerate a 40 kg mass by 4 m/s²?

F = ma

F = (40 kg)(4 m/s²)

F = 160 N

- A 4.0 kg shotput is thrown with 30 N of force. What is its acceleration?

a = F ÷ m

a = (30 N) ÷ (4.0 kg)

a = 7.5 m/s²

- How much force, or thrust, must a 30 000- kg jet plane develop to achieve an acceleration of 1.5 m/s2?

F = ma
F = (30 000 kg)(1.5 m/s²)
F = 45 000 kg.m/s²
F = 45 000 N
F = 4.5 x 10⁴ N

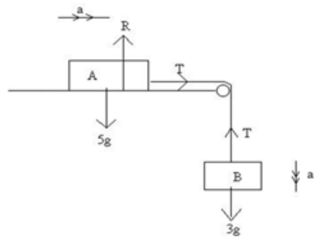
Using Newton's Second Law on body A (horizontally):

(F = ma)
T = 5a (1)

Using Newton's Second Law on body B (vertically):

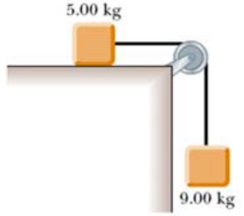
3g - T = 3a (2)

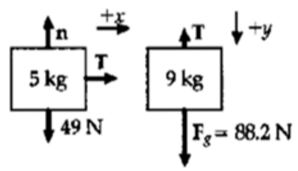
Solving (1) and (2) simultaneously:
3g - 5a = 3a
8a = 3g
a = 3g/8
T = 15g/8



Therefore the acceleration is 3.68 ms⁻² and the tension is 18.4 N

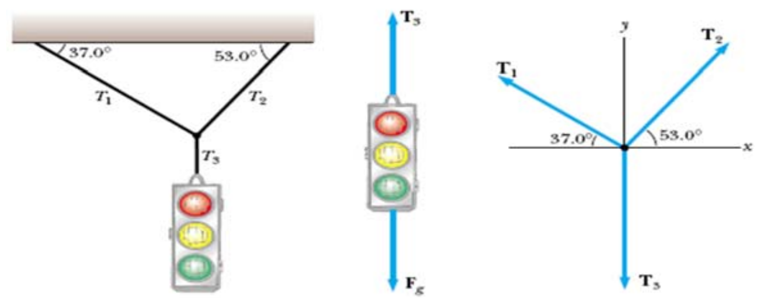
A 5.00-kg object placed on a frictionless, horizontal table is connected to a string that passes over a pulley and then is fastened to a hanging 9.00-kg object, as in Figure P5.24. Draw free-body diagrams of both objects. Find the acceleration of the two objects and the tension in the string.





Example:

A traffic light weighing 122 N hangs from a cable tied to two other cables fastened to a support, as in Figure 5.10a. The upper cables make angles of 37.0° and 53.0° with the horizontal. These upper cables are not as strong as the vertical cable, and will break if the tension in them exceeds 100 N. Will the traffic light remain hanging in this situation, or will one of the cables break?



Force	x Component	y Component
$\mathbf{T}_1$	$-T_1 \cos 37.0°$	$T_1 \sin 37.0°$
$\mathbf{T}_2$	$T_2 \cos 53.0°$	$T_2 \sin 53.0°$
$\mathbf{T}_3$	0	-122 N

Knowing that the knot is in equilibrium ($\mathbf{a} = 0$) allows us to write

(1) $\sum F_x = -T_1 \cos 37.0° + T_2 \cos 53.0° = 0$

(2) $\sum F_y = T_1 \sin 37.0° + T_2 \sin 53.0° + (-122 \text{ N}) = 0$

the weight of the light. We solve (1) for T_2 in terms of T_1 to obtain

(3) $$T_2 = T_1\left(\frac{\cos 37.0°}{\cos 53.0°}\right) = 1.33 T_1$$

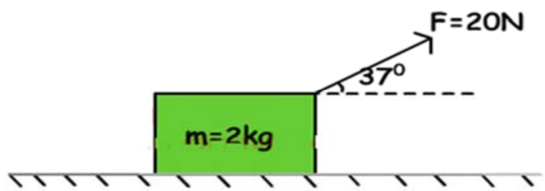
This value for T_2 is substituted into (2) to yield

$$T_1 \sin 37.0° + (1.33 T_1)(\sin 53.0°) - 122 \text{ N} = 0$$

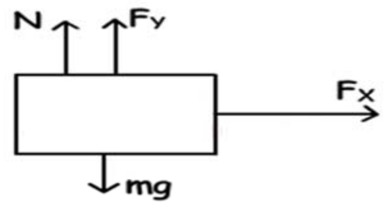
$$T_1 = 73.4 \text{ N}$$

$$T_2 = 1.33 T_1 = 97.4 \text{ N}$$

1. A box is pulled with 20N force. Mass of the box is 2kg and surface is frictionless. Find the acceleration of the box.



We show the forces acting on the box with following free body diagram.



X component of force gives acceleration to the box.

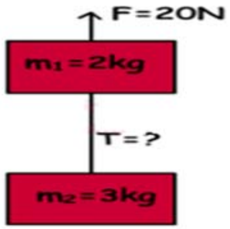
F_x=F.cos37°=20.0,8=16N

F_x=m.a

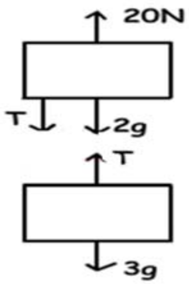
16N=2kg.a

a=8m/s^2

5. When system is in motion, find the tension on the rope.



Free body diagrams of boxes are given below.



m_1: 20 - T - 2g = - 2.a

m_2: T - 3g = - 3.a

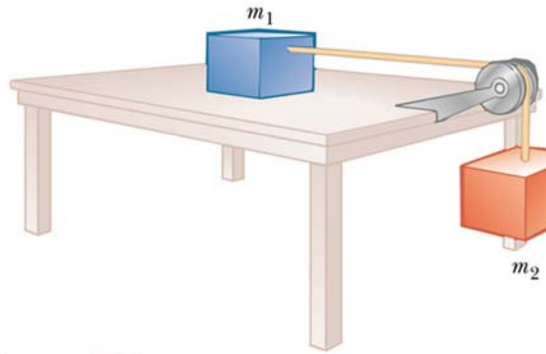
20 - 5g = - 5.a

a=g-4 putting it into m_1 equation;

20 - T - 2g= - 2(g-4)

T=12N

Example



Given m_1 = 10 kg and m_2 = 5 kg:

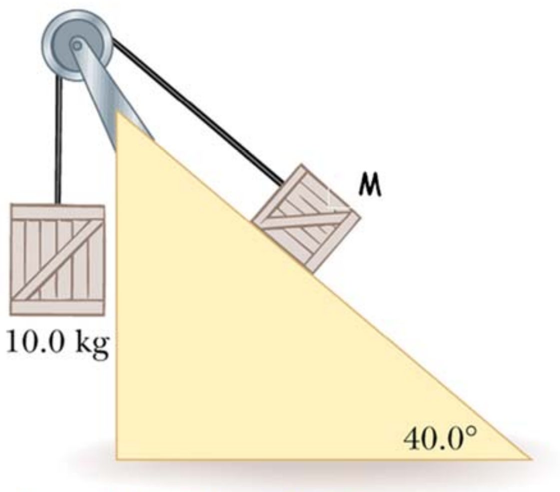
a) What value of μ_s would stop the block from sliding?

b) If the box is sliding and μ_k = 0.2, what is the acceleration?

c) What is the tension of the rope?

a) μ_s = 0.5 b) a=1.96 m/s^2 c) 39.25 N

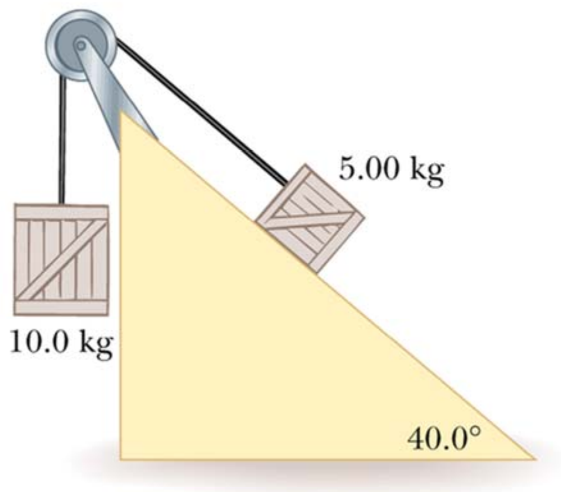
Example



Find M such that the box slides at constant v

M=15.6 kg

Example



Find the acceleration and the tension

a = 4.43 m/s^2, T= 53.7 N

Friction

- **The friction force acts in a direction parallel to the area of contact, and opposes the motion or the tendency to move.**

"When 2 things are in contact with each other, there will be friction acting between them"

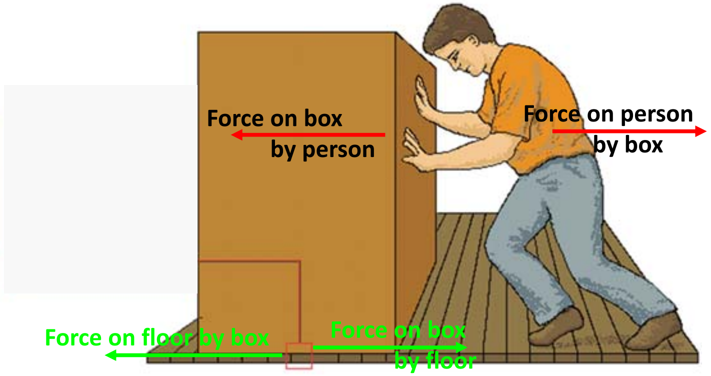
friction force depends on two things:

- The normal force (N)
- The nature of the surfaces involved (μ)

$$F_{friction} = \mu \cdot N$$

- The friction force **does not** depend on the surface area (contact area).

Friction is a Force



It's the sum of all the forces that determines the acceleration.
Every force has an equal & opposite partner.

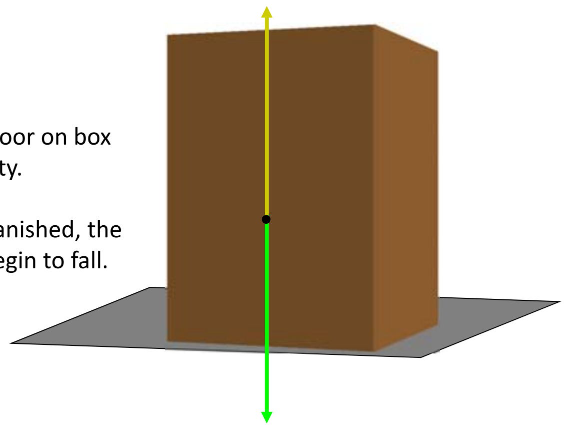
Friction Mechanism

Corrugations in the surfaces grind when things slide.
Lubricants fill in the gaps and let things slide more easily.

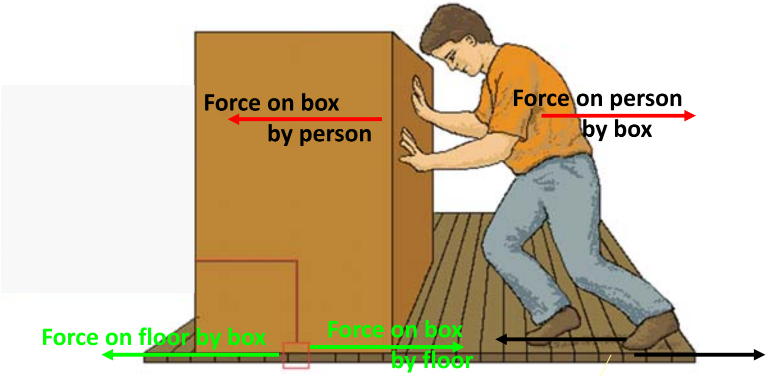
Why Doesn't Gravity Make the Box Fall?

Force from floor on box cancels gravity.

If the floor vanished, the box would begin to fall.



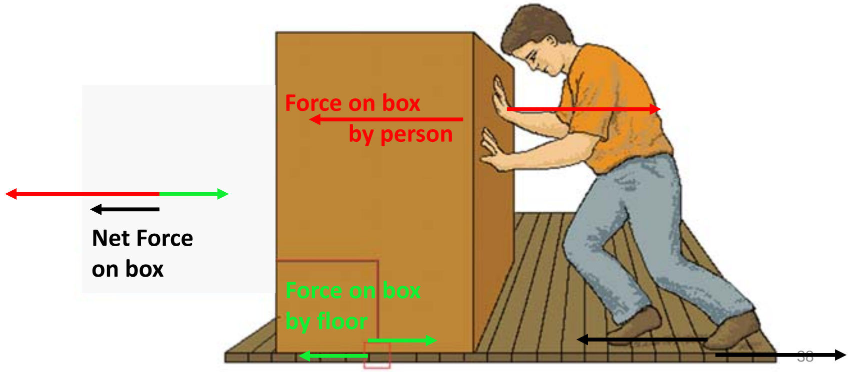
What's missing in this picture?

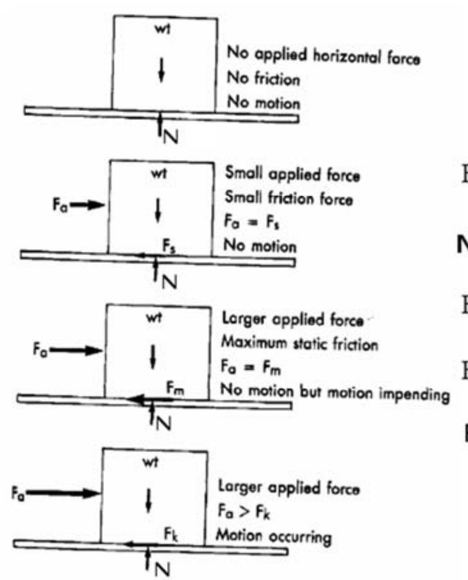


A pair of forces acting between person and floor.

Don't all forces then cancel?

- How does anything ever move (accelerate) if every force has an opposing pair?
- The important thing is the net force on the object of interest





F_a = Action Force

N = Normal Reaction Force

F_s = Static Friction Force

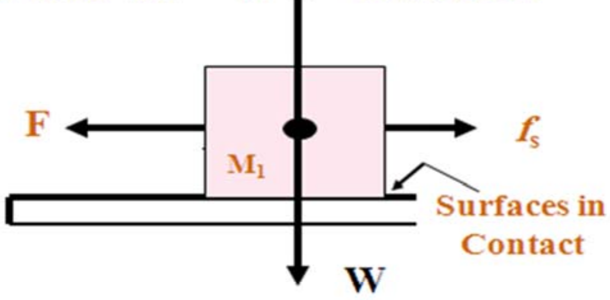
F_k = Kinetic Friction Force

F_m = Maximum static friction

Magnitude of Friction

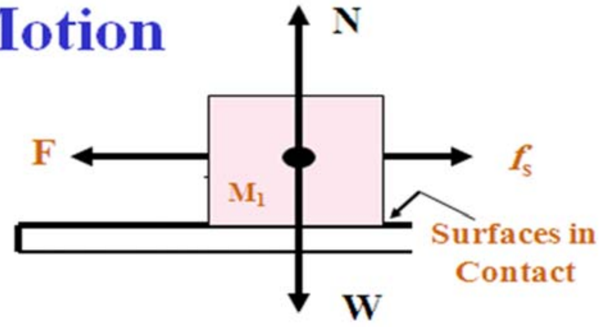
- Two factors govern the magnitude of the force or maximum static friction or kinetic friction in any situation: the coefficient of friction, represented by the small Greek letter mu (μ), and the normal (perpendicular) reaction force (N).
- $F = \mu N$

Frictional Forces Occur When Materials are in Contact



F = Force Causing Motion (Pull on Scale)
F_s = Force of Static Friction (Resists Motion)
N = Force Normal Holds Surfaces in Contact
W = Weight of Object (Mass x Gravity)

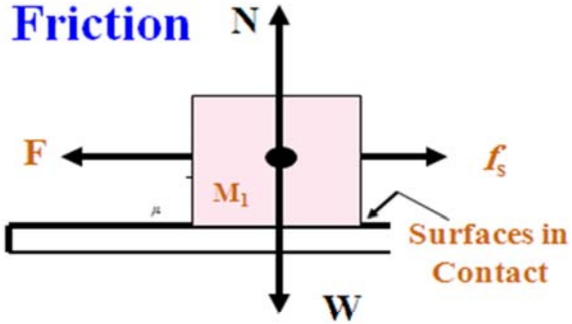
Friction is a Force That Resists Motion



The Pink Block M_1 Will not Move Until the Force F (Pull on the scale) Exceeds the Force of Static Friction f_s.

$$\mu_s = \frac{F}{W}$$

Coefficient of Static Friction



μ_s = Coefficient of Friction
F = Force Required to Cause Motion
W = Weight of Object

Consider 2 Types of Friction

F_s **Force of Static Friction**

This value represents the relative force necessary to make an object move

F_k **Force of Kinetic Friction**

This value represents the relative force necessary to keep an object moving at a constant rate

The following *empirical* laws hold true about friction:

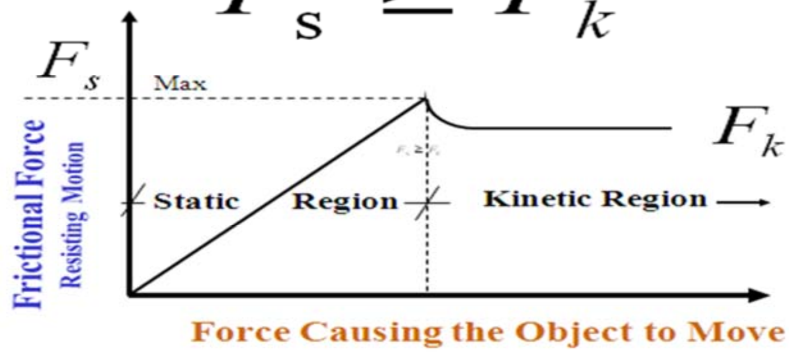
- Friction force, f, is proportional to normal force, n.

$$f_s \leq \mu_s n \qquad f_k = \mu_k n$$

- μ_s and μ_k: coefficients of static and kinetic friction, respectively
- Direction of frictional force is opposite to direction of relative motion
- Values of μ_s and μ_k depend on nature of surface.
- μ_s and μ_k *don't* depend on the area of contact.
- μ_s and μ_k *don't* depend on speed.
- $\mu_{s,\,max}$ is usually a bit larger than μ_k.
- Range from about 0.003 (μ_k for synovial joints in humans) to 1 (μ_s for rubber on concrete). See table 5.2 in book.

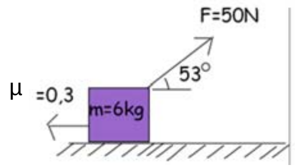
- As more force is applied, the friction force **increase**. The friction force will continue to **increase**

$$F_s \geq F_k$$



Example 50N of force is applied to the 6 kg box. If the coefficient of friction is 0, 3, find the acceleration of the box.

Components of force;
Fx=F.cos53=50N.0,6=30N
Fy=F.sin53=50N.0,8=40N

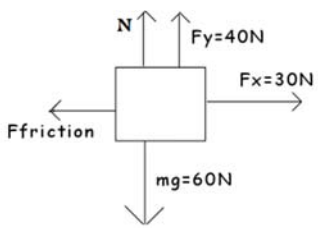


N = mg – Fy

N =60N-40N=20N

And friction force is;

Ffriction=μ. **N** =0, 3.20N=6N



Net force in –Y to Y is zero, in other words box is in equilibrium in this direction.

However, in –X +X direction net force is not zero so there is a motion and acceleration in this direction.

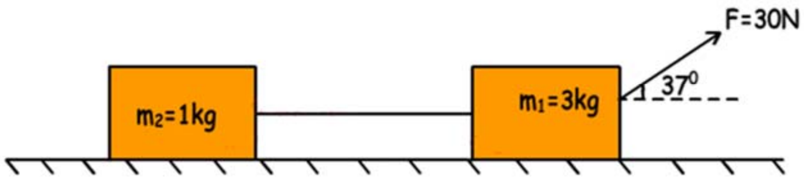
Fnet=m.a

Fx-Ffriction=m.a

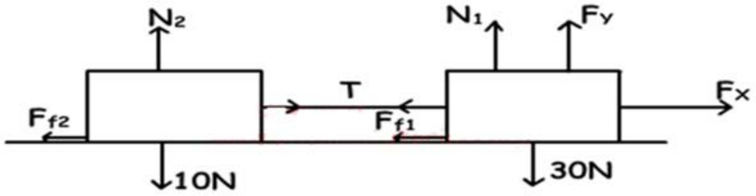
30N-6N=6kg.a

a=4m/s²

Picture given below shows the motion of two boxes under the effect of applied force. Friction constant between the surfaces is μ_k =0,4. Find the acceleration of the boxes and tension on the rope. ($g=10 m/s^2$, $\sin 37^0=0{,}6$, $\cos 37^0=0{,}8$)



Free body diagram of these boxes given below.



Components of force,

$F_x = F \cos 37^0 = 30 \times 0.8 = 24N$

$F_y = F \sin 37^0 = 30 \times 0.6 = 18N$

$N_1 = m\,g - F_y = 30 X 18 = 12N$

$N_2 = 10N$

F_{f_1} and F_{f2} are the friction forces acting on boxes.

$F_{f_1} = \mu_k N_1 = 0.4 \times 12 = 4.8N$ and $F_{f2} = \mu_k N_2 = 0{,}4 \times 10 = 4N$

We apply Newton's second law on two boxes.

m_1: $F_{net} = m\,a$

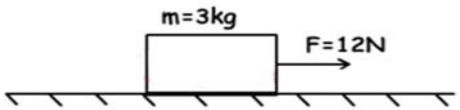
$24 - T - F_{f_1} = 3\,a$ $\quad$ $24 - T - 4{,}8 = 3\,a$

m_2: $T - F_{f2} = 1\,a$ $\quad$ $T - 4 = a$

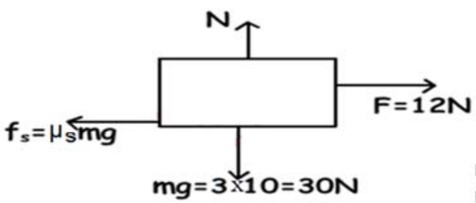
$a = 3.8\ m/s^2$

$T = 7.8\ N$

Position time graph of the box is given below. Find the friction constant between the box and surface? ($g = 9.8\ m/s^2$)



Slope of the graph gives us velocity of the box. Since the slope of the position time graph is constant, velocity of the box is also constant. As a result, acceleration of the box becomes zero.



$F_{net} = F - f_s = m\,a = 0$

$F = f_s$

$f_s = 12$

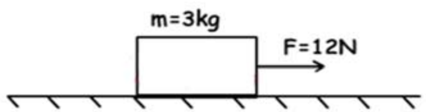
$\mu_s\, mg = 12$

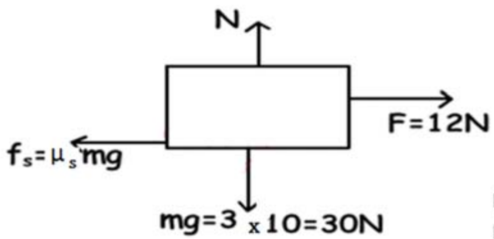
$\mu_s \times 3 \times 10 = 12$

$\mu_s = 0.4$

If the box moves with constant velocity

acceleration of the box becomes zero.





$F_{net} = F - f_s = m.a = 0$

$F = f_s$

$f_s = 12$

$\mu_s\ mg = 12$

$\mu_s\ 3 \times 10 = 12$

$\mu_s = 0{,}4$