CHAPTER 3: DYNAMICS

CPP 1113 Principles of Physics

contents

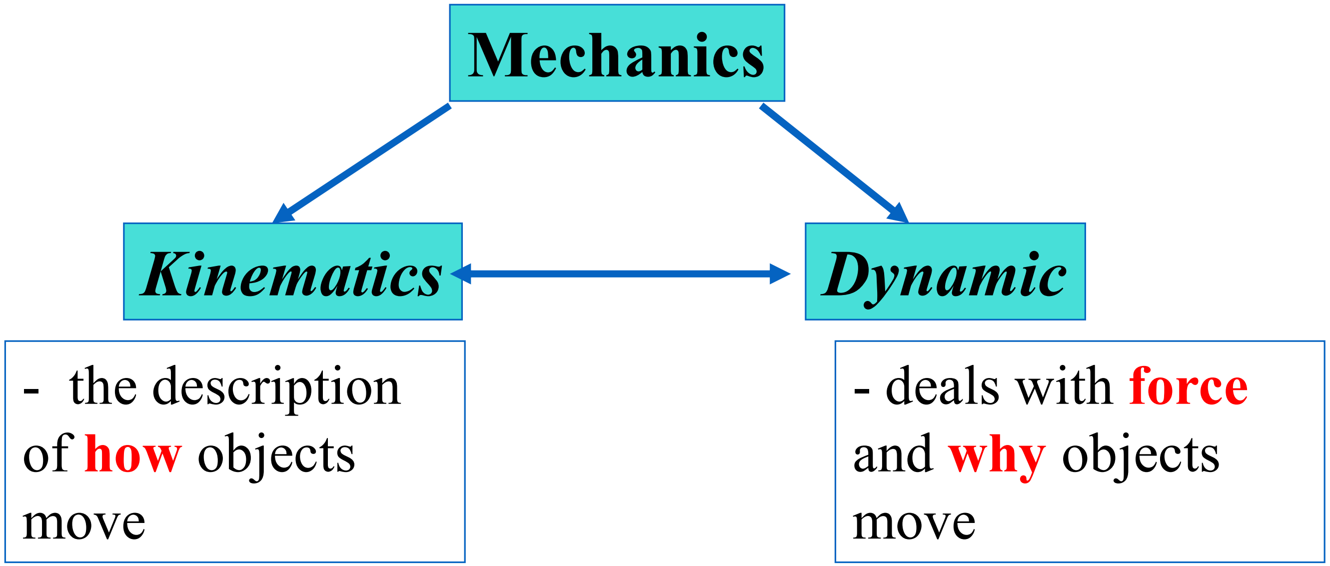
At the end of this chapter you should be able to :

- Relate force and motion and explain what is meant by a net or unbalanced force.
- State and explain Newton’s first law of motion, and describe inertia and its relationship to mass.
- State and explain Newton’s second law of motion and apply it to physical situations.
- Apply Newton’s second law, including the component form, to various situations.
- State and explain Newton’s third law of motion and identify action-reaction pairs.

At the end of this chapter you should be able to :

- Explain the meaning of apparent weight and weightlessness.
- Explain the causes of friction and how it is described using coefficient of friction.
- Explain the different between static and kinetic friction force.

Before Start ……



Before Start ……

- **Dynamics** : deals with **force** and **why** objects move as they do.
  - In this part we will solve the following questions:
    - What makes an object at rest begin to move ?
    - What causes a body to accelerate or decelerate ?
    - What is involved when an object moves in a circle ?

Before Start ......

Force

Translations

$$m\,a = m\frac{dv}{dt}$$

$$m\,a = m\left(\frac{v_f - v_i}{t_f - t_i}\right)$$

Rotations

$$m\,a_c = m\left(\frac{v^2}{r}\right)$$

In the chapter of gravitation force

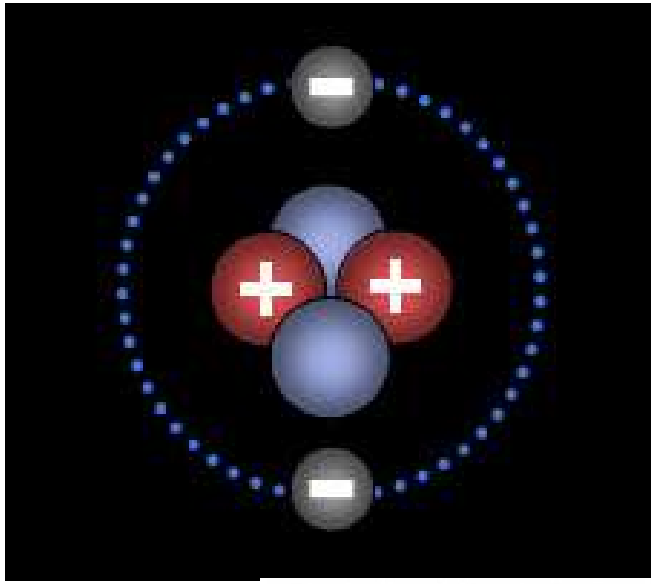
Vibrations

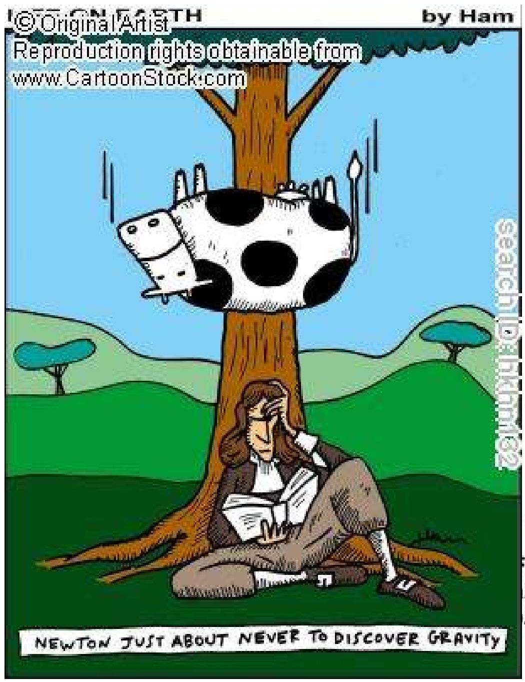
$$m\,a = -m\,\omega^2\,x$$

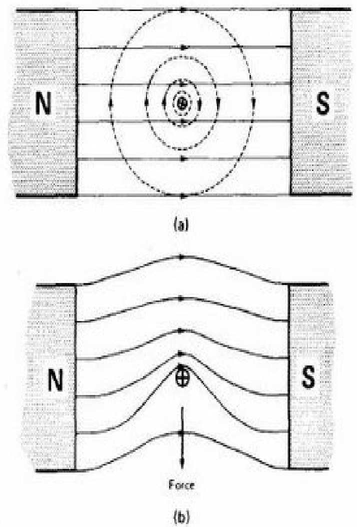
Will be discussed in the chapter of Oscillatory motions

Before Start ……

- Type of Force
  - Strong nuclear force
    - subatomic particles
  - Electromagnetic force
    - electric charges
  - Weak nuclear force
    - radioactive decay processes
  - Gravity
    - attraction between objects







igure 2.32
. Magnetic field due to magnet and conductor.
. Resulting magnetic field pushes the conductor downward.

3.1 Force and net force

- In other word, force is applied to cause of acceleration of an object.
- It is a vector quantity.
- There must be a net force on an object for the object to changes its velocity or to accelerate.
- Symbol : F

Unit : Newton, N / kg ms^{-2}

$$\boxed{F = ma}$$

$$F = kg \times ms^{-2}$$
$$= kgms^{-2}$$
#

** Free body diagram

$F_f = \mu N$ ← force of normal

coefficient of friction

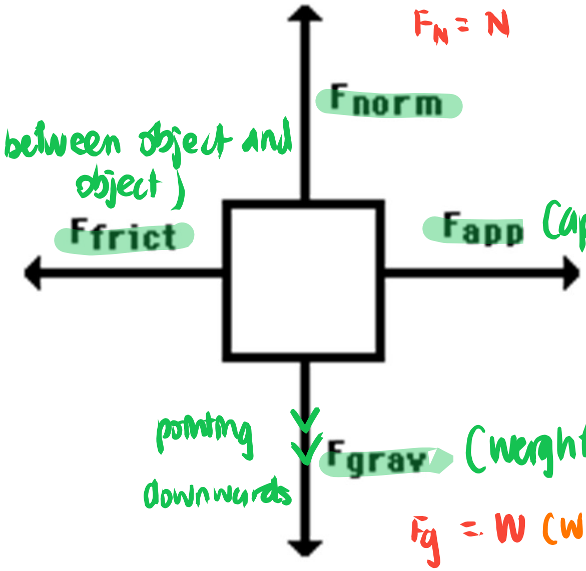
$\boxed{0 < \mu < 1}$

frictionless   high friction force

- Diagrams used to show the relative magnitude and direction of all forces acting upon an object in a given situation.

$F_N = N$

(between object and object)



(applied externally)

pointing downwards

(weight)

$F_g = W$ (weight)

$= mg$

mass

gravitational acceleration, $9.81\ ms^{-2}$

F_{App}
An applied force is a force which is applied to an object by a person or another object.

F_{grav}
Force with which the earth, moon, or other massively large object attracts another object towards itself. The weight of the object.

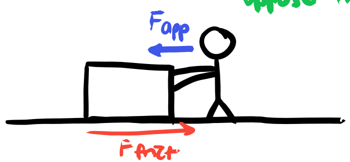
F_{norm}
Support force exerted upon an object which is in contact with another stable object.

Contact force (must physically contacted)

F_{frict}
force exerted by a surface as an object moves across it or makes an effort to move across it.

(contact force, have tendency to move)

oppose the direction of movement



3.1 Force and net force – Free Body Diagram

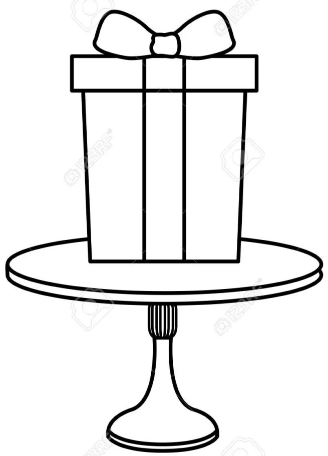
- Step to draw a net force diagram of a book sitting on desk.
  - We isolate the book and then we analyze the force acting on the book.
  - There are 2 forces acting on the book.
    - Gravitational force (Weight)
    - Supporting force on the book by desk.
  - Gravitational force always present if we dealing with object on the earth.
  - Whenever an object make a physical contact with another object, a force results.
    - Here the book makes a contact with desk and so there is a supporting force.
  - Normally the contact forces are perpendicular to the contact surface and therefore called normal forces

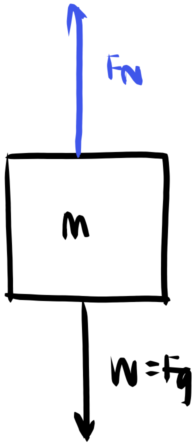
** Free body diagram

- Example

m

A 20.0 kg box rests on a table. What is the weight of the box and the normal force acting on it?





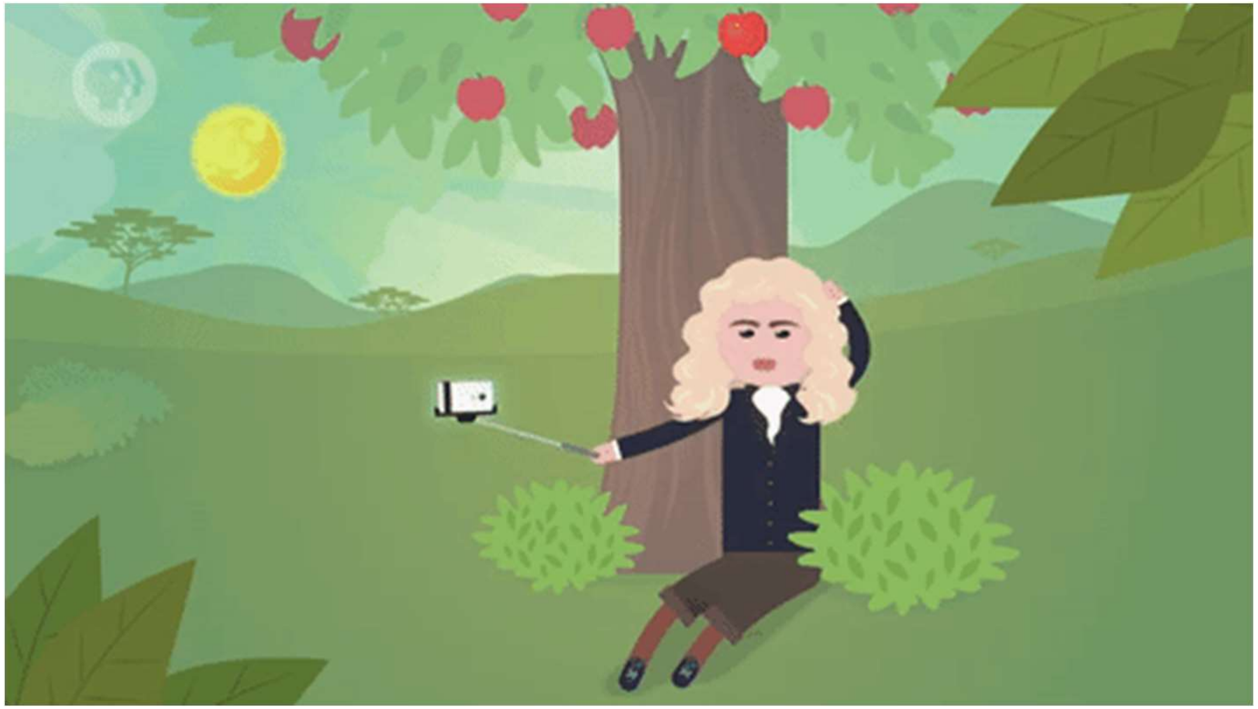
Weight, $W = 20 \times 9.81$

$= 196.2\,N$

$F_N = W$

$= 196.2\,N$

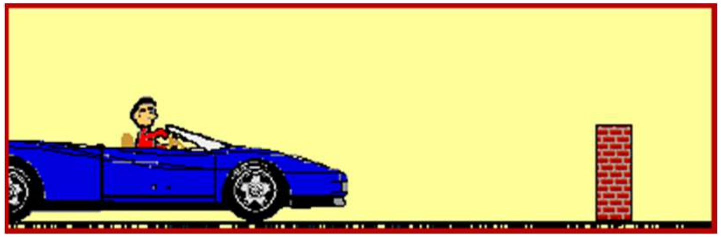
3.2 Newton's Law of Motion



Newton Force

3.2 Newton’s Law of Motion

- 3.2.1 Newton’s First Law = Law of Inertia



“Every body continues in its state of rest or of uniform speed in a straight line unless acted on by a nonzero net force.” by Newton

3.2 Newton's Law of Motion

- According to Newton's first law
  - If Net force is zero
    - An object at rest will remain at rest.
      - There is no change in velocity
      - Acceleration is 0.
    - Object in motion (Same speed and direction) will keep with constant velocity.
      - There is no change in velocity
      - Acceleration is 0
- Mathematic representation

$$\sum F = 0 \text{ then } a = 0$$

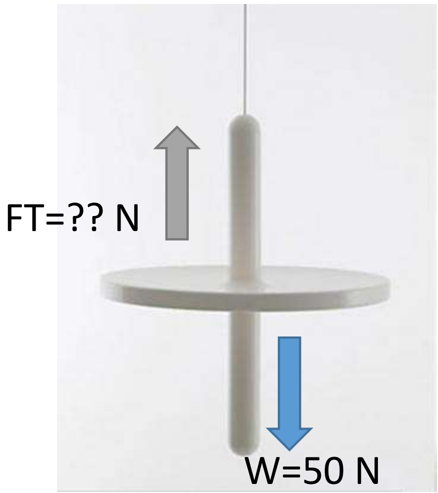
Object is in equilibrium

3.2 Newton’s Law of Motion

- Law of inertia
  - The tendency of a body to maintain its state of rest or uniform motion in a straight line.

- Example

The object in the figure weighs is 50N and is supported by a cord. Find the tension in the cord.



Since the object is in rest condition, therefore, there are 2 forces act on it in order to achieve equilibrium condition.

Mathematic representation:

$$\sum F_y = 0$$

$$\sum F_y = FT - W$$

$$0 = FT - 50$$

$$FT = 50N$$

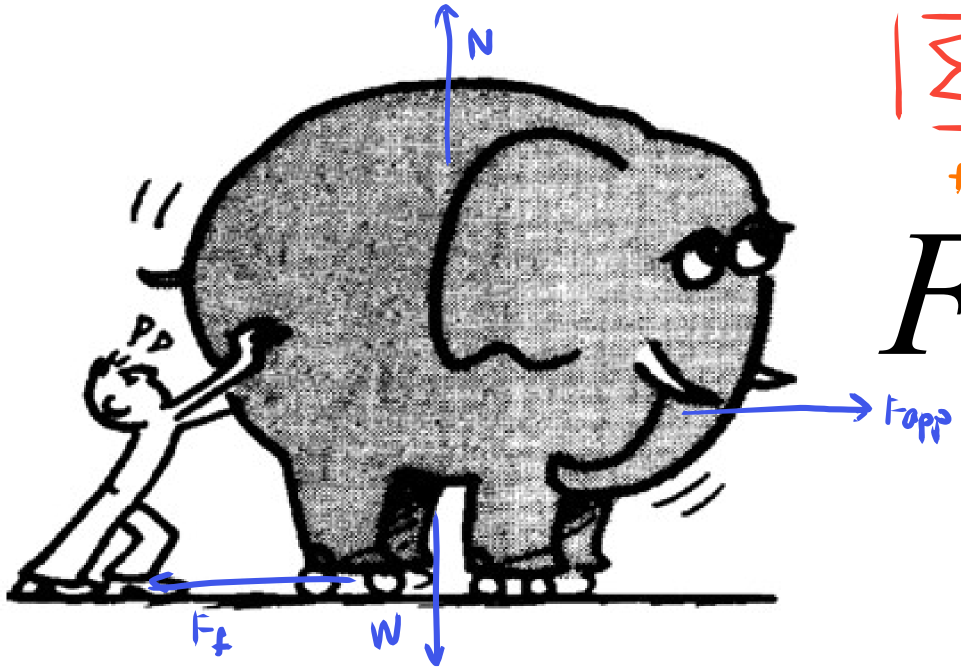
3.2 Newton's Law of Motion

- 3.2.2 Newton's Second Law

mass

$$\boxed{\sum F = ma}$$

force acceleration



$$F \propto a$$

$$\sum F_x = +F_{app} - F_f = ma$$

$$\sum F_y = +N - W = ma$$

3.2 Newton's Law of Motion

- 3.2.2 Newton's Second Law

"The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object." by Newton

$$F \propto a$$

$$\sum F = ma$$

3.2 Newton's Law of Motion

- Example

  A net force of 255 N accelerates a bike and a rider at 2.20 m/s^2. What is the mass of the bike and rider?

$\boxed{F=ma}$

$255 = m(2.20)$

$m = 115.9091\ kg$

3.2 Newton's Law of Motion

- Example

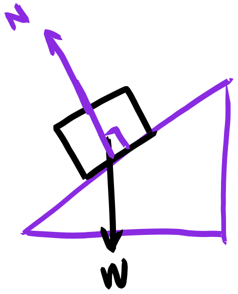
How much tension must a rope withstand if it is used to accelerate a 1050 kg car horizontally at 1.2 m/s^2? Ignore friction.

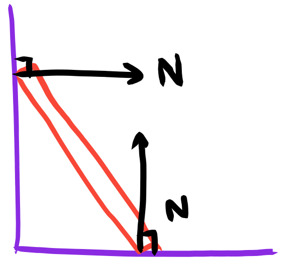
$F = ma$

$= 1050(1.2)$

$= 1260 N$

$\boxed{N = W = F_g = mg}$



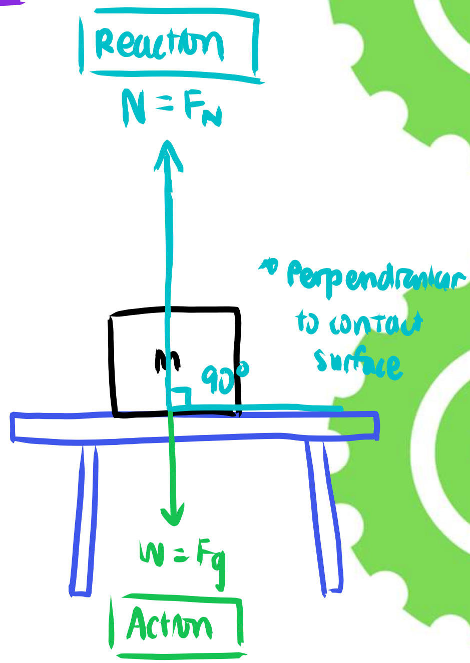


3.2 Newton's Law of Motion

- 3.2.3 Newton's Third Law = Law of Action and Reaction

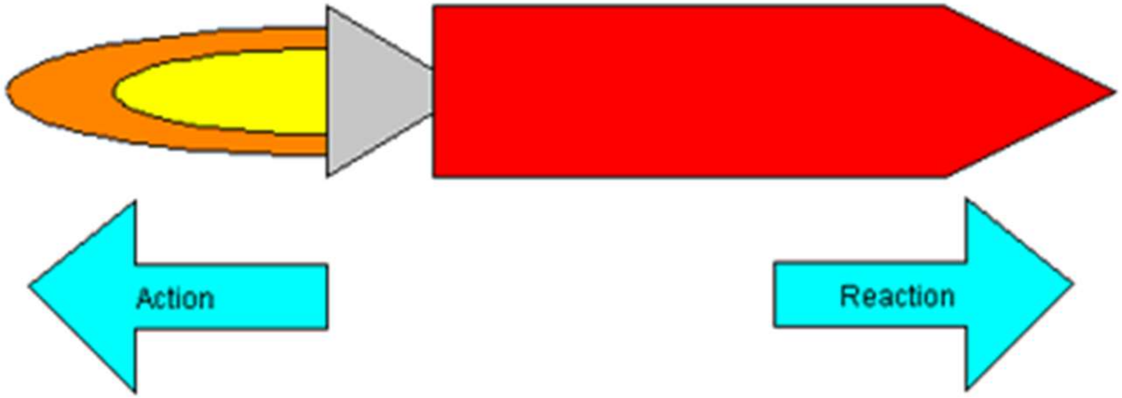
"Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first." by Newton

This means that for every force there is a reaction force that is equal in size, but opposite in direction



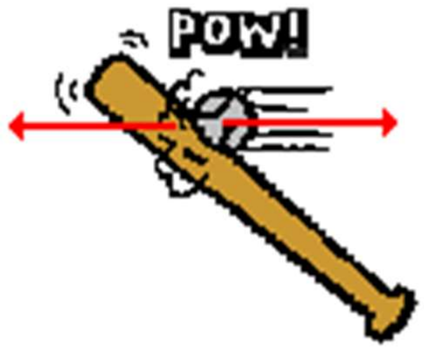
3.2 Newton's Law of Motion

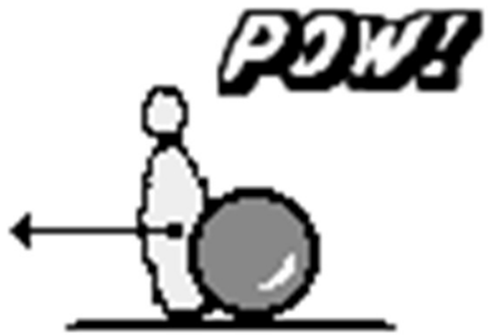
- 3.2.3 Newton's Third Law



Action : a rocket pushes out exhaust...
Reaction: the exhaust pushes the rocket forward.

3.2 Newton's Law of Motion

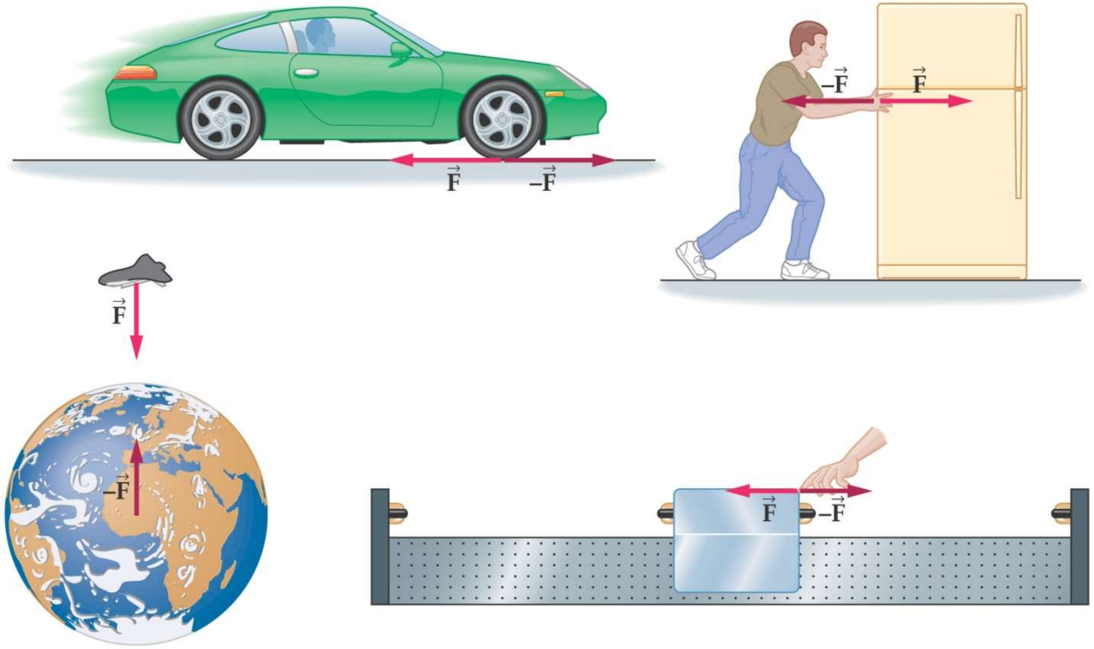




Action:	The baseball forces the bat to the left
Reaction :	the bat forces the ball to the right.
Action:	Bowling ball pushes pin leftwards.
Reaction :	Pin pushes bowling ball rightward.

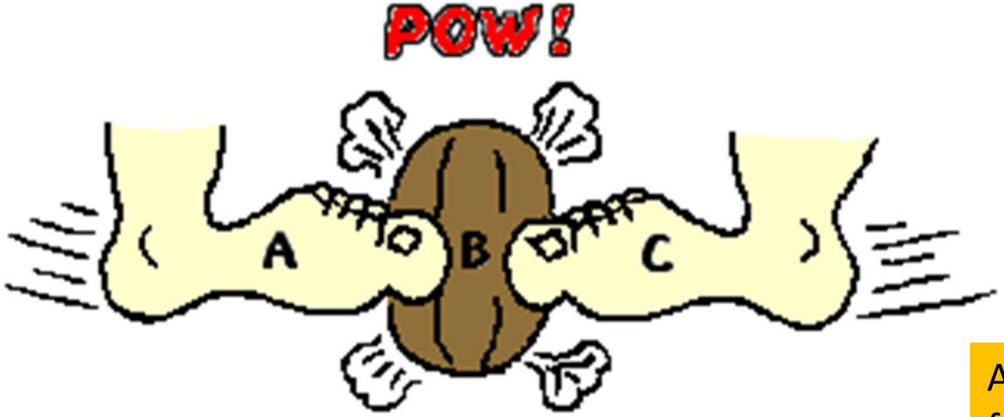
3.2 Newton’s Law of Motion

- 3.2.3 Newton’s Third Law



3.2 Newton's Law of Motion

Exercise



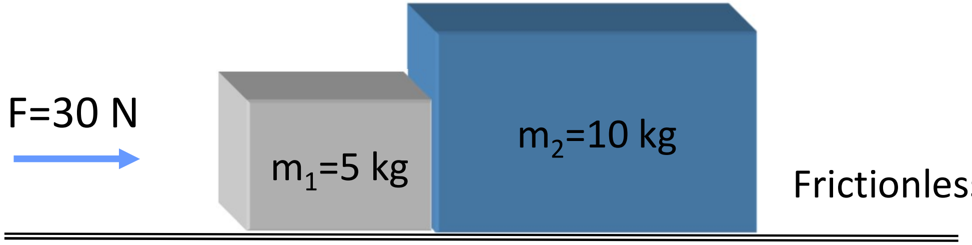
Consider the interaction depicted below between foot A, ball B, and foot C. The three objects interact simultaneously (at the same time). Identify the <u>two pairs</u> of action-reaction forces. Use the notation "foot A", "foot C", and "ball B" in your statements.

Action :
foot A pushes ball B to the right
Reaction:
ball B pushes foot A to the left

Action:
foot C pushes ball B to the left
Reaction:
ball B pushes foot C to the right

3.2 Newton's Law of Motion

- Example



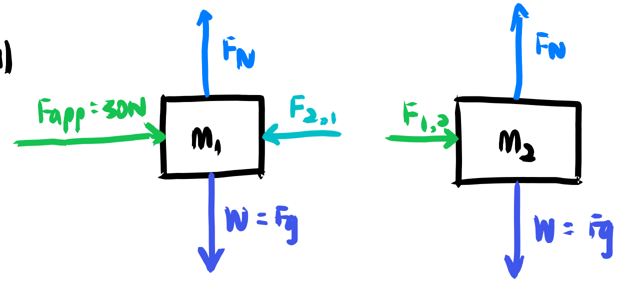
a) Draw the free body diagram for each block.

b) Determine the acceleration of the system

c) Determine the net force on each block

d) Determine the force exerts on m_2

(a)



(b)

$\Sigma F = ma$

$30 = (5+10)a$

$a = 2\ m\,s^{-2}$

(c)

F_{21} $\quad$ $F_{app} = 30N$

$\Sigma F_1 = m_1 a$

$-F_{21} + F_{app} = m_1 a$

$-F_{21} + 30 = 5(2)$

$-F_{21} = -20$

$F_{21} = 20N$

F_{12}

$\Sigma F_2 = m_2 a$

$F_{12} = m_2 a$

$F_{12} = 10(2)$

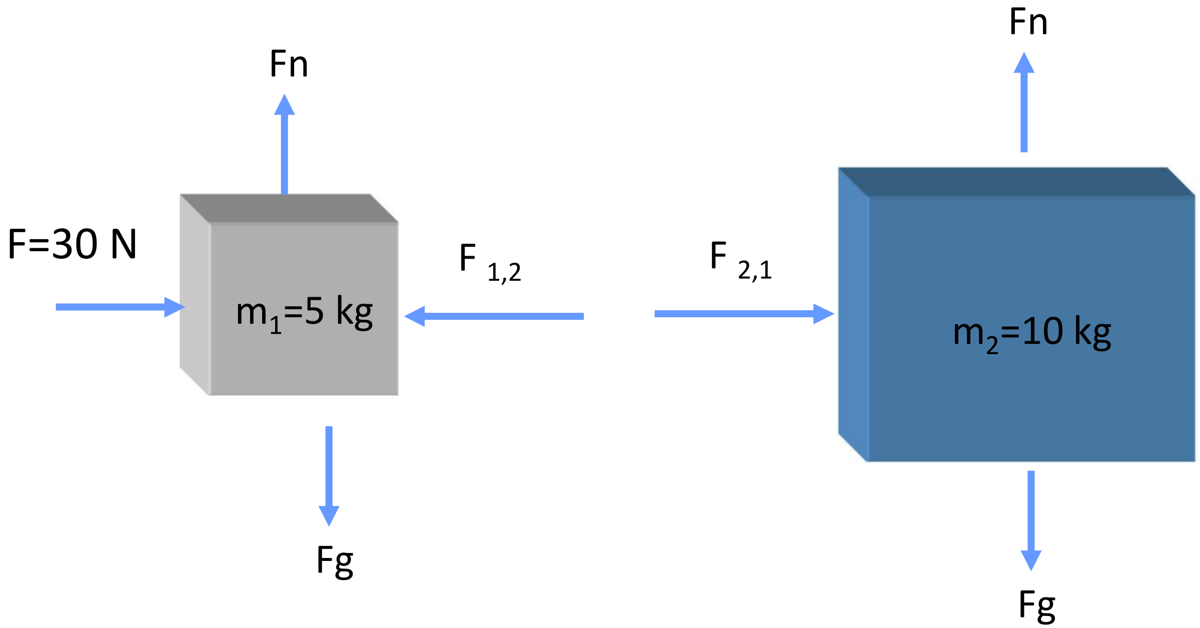
$F_{12} = 20N$

(d) $F_2 = 20N$ # (F_{12})

coming from first object

3.2 Newton's Law of Motion

a.) Draw the free body diagram for each block.



3.2 Newton's Law of Motion

b.) Determine the acceleration of the system

$$\sum F_x = ma$$

$$30 = (5+10)a$$

$$a = \frac{30}{15}$$

$$= 2ms^{-2}$$

3.2 Newton's Law of Motion

c.) Determine the net force on each block

Net force of Block m_1

$$\begin{aligned} F_{net} &= F - F_{12} \\ &= m_1 a \\ &= (5kg)(2ms^{-2}) \\ &= 10N \end{aligned}$$

Net force of Block m_2

$$\begin{aligned} F_{net} &= m_2 a \\ &= (10kg)(2ms^{-2}) \\ &= 20N \end{aligned}$$

3.2 Newton’s Law of Motion

- Determine the force exerts on m_2

$$F - F_{12} = m_1 a$$

$$30 - F_{12} = 5kg(2ms^{-2})$$

$$F_{12} = 30 - 10$$

$$= 20N$$

$$F_{12} = F_{21}$$

$$\therefore F_{21} = 20N$$

3.2 Newton’s Law of Motion

- More exercise will be discussed in the tutorial section.

3.3 Weight - the force of gravity

- Weight
  - Force that pulls the body directly toward the earth.
  - Force of gravity acting on body

$$F_G = mg$$

Unit : Newton, g = 9.8ms^{-2}

3.3 Weight - the force of gravity

- Weightlessness
  - When the acceleration of the person and the enclosure are equal, the person is said to be apparently weightless
    - Even though the weight is not zero

3.3 Weight - the force of gravity

- Weightlessness – lift case

Case 1

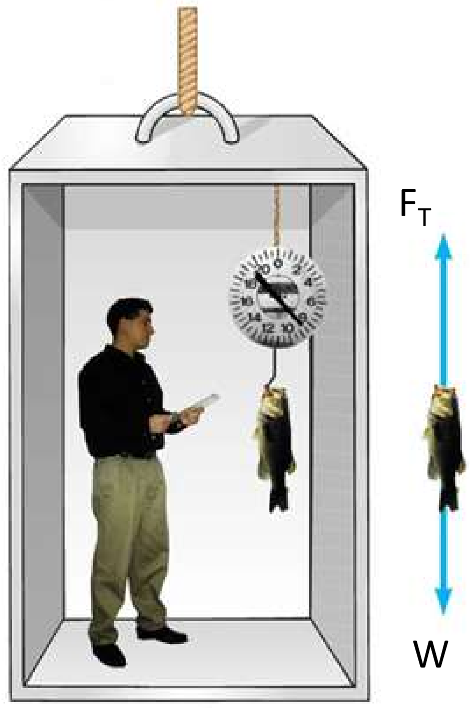
Non-accelerating lift (a=0)

$$\sum F = 0$$

$$\sum F = F_T - W$$

$$= 0$$

$$F_T = W$$



3.3 Weight - the force of gravity

- Weightlessness – lift case

Case 2

Ascending lift

$$\sum F = ma$$

$$F_T + (-W) = ma$$

$$F_T - W = ma$$

$$F_T = ma + W$$

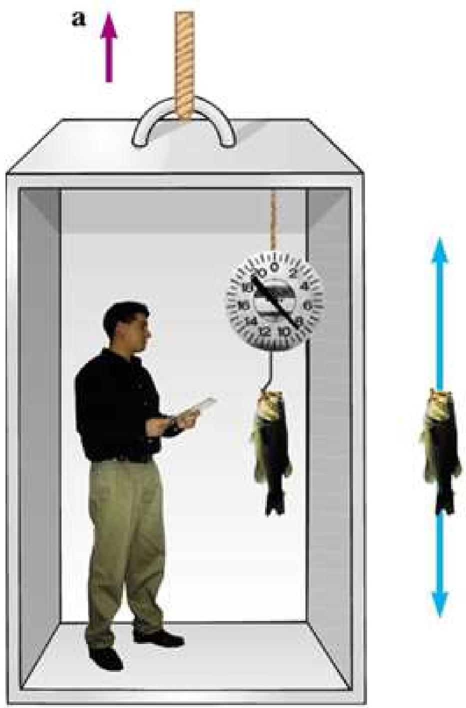
$$= ma + mg$$

$$= m(a+g)$$

$$\therefore F_T > mg$$

- With an upward acceleration a, we see that F_T is more than mg

- The scale indicates that the fish weights more than the true weight.



3.3 Weight - the force of gravity

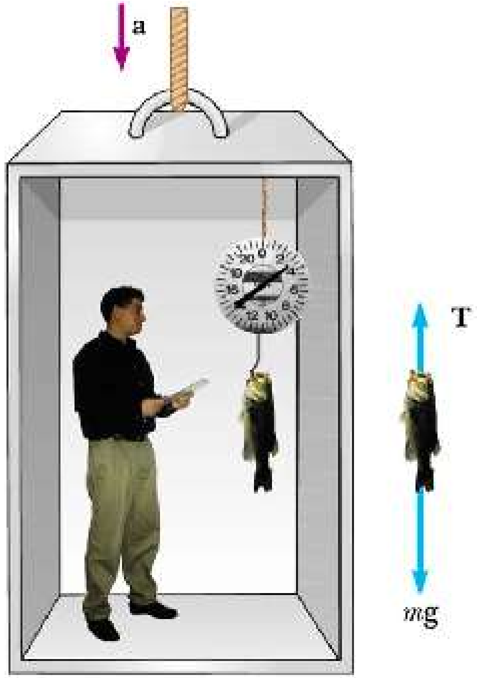
- Weightlessness – lift case

Case 3

Descending lift (a<g)

$$\sum F = ma$$
$$-F_T + W = ma$$
$$W - F_T = ma$$
$$F_T = W - ma$$
$$= mg - ma$$
$$= m(g - a)$$
$$\therefore F_T < mg$$

- With an downward acceleration a, we see that F_T is less than mg
- The scale indicates that the fish weights less than the true weight.



3.3 Weight - the force of gravity

- Weightlessness – lift case

Case 3

Free fall lift (a=g)

$$\sum F = ma$$

$$\sum F = mg$$

$$W - F_T = mg$$

$$F_T = W - mg$$

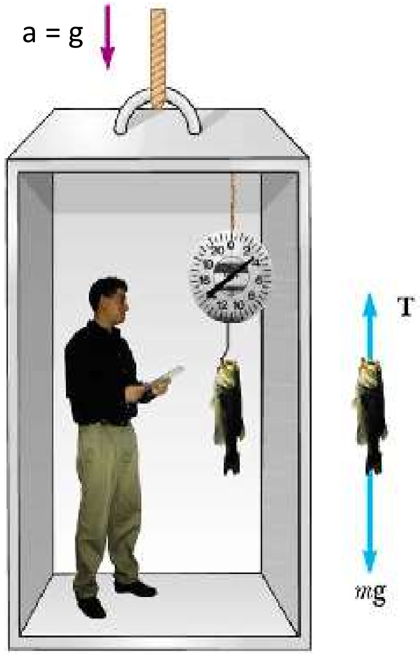
$$= mg - mg$$

$$= m(g - g)$$

$$\therefore F_T = 0$$

•With an downward acceleration a, and a = g, free fall (weightless) condition occurs.

•The scale indicates that the fish weights is 0 N.



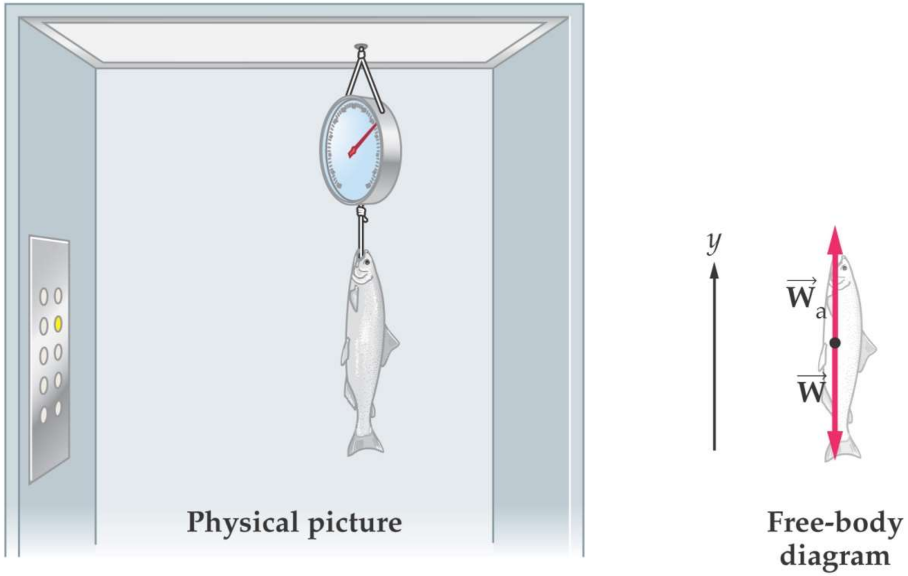
3.3 Weight - the force of gravity

Summary

Acceleration, a (ms^{-2})	Lift movement Direction	Formula
$a=0$	None	$F_T=mg$
$a>0$	$\uparrow$	$F_T=m(g+a)$
$0<a<g$	$\downarrow$	$F_T=m(g-a)$
$a=g$	$\downarrow$	$F_T=m(g-g)=0$

3.3 Weight - the force of

- Exercise



A 5.0-kg salmon is weighed by hanging it from a fish scale attached to the ceiling of an elevator. Let g=9.8ms^{-2}What is the apparent weight of the salmon if the elevator

(a) is at rest,

(b) moves with an upward acceleration of 2.5 m/s/s, or

(c) moves with a downward acceleration of 3.2 m/s/s?

3.3 Weight - the force of gravity

- Solution

a.)

$$
\begin{aligned}
F_T &= W \\
&= mg \\
&= 5(9.8) \\
&= 49N
\end{aligned}
$$

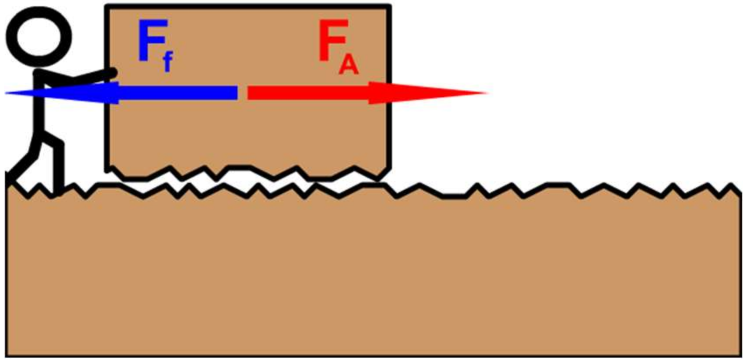
b.)

$$
\begin{aligned}
F_T &= m(g+a) \\
&= 5(9.8+2.5) \\
&= 61.5N
\end{aligned}
$$

c.)

$$
\begin{aligned}
F_T &= m(g-a) \\
&= 5(9.8+3.2) \\
&= 33N
\end{aligned}
$$

3.4 friction force



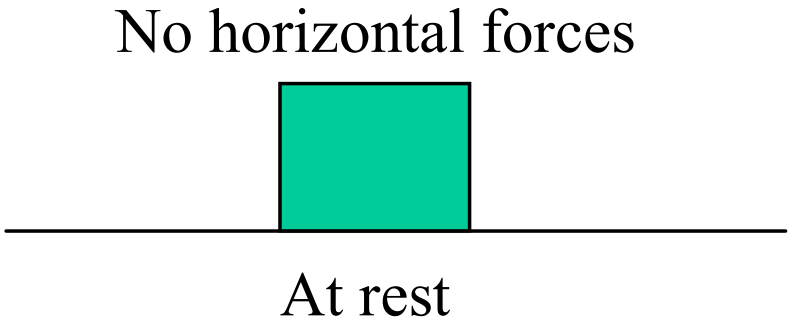
- When a body is in motion and the motion is taken in place on a surface, air or water, there is resistance to the motion because the body interacts with its surroundings.

3.4 friction force

- Friction is a force that is created whenever two surfaces move or try to move across each other.
    - Friction always opposes the motion or attempted motion of one surface across another surface.
    - Friction is dependant on the texture of both surfaces.
    - Friction is also dependant on the amount of contact force pushing the two surfaces together

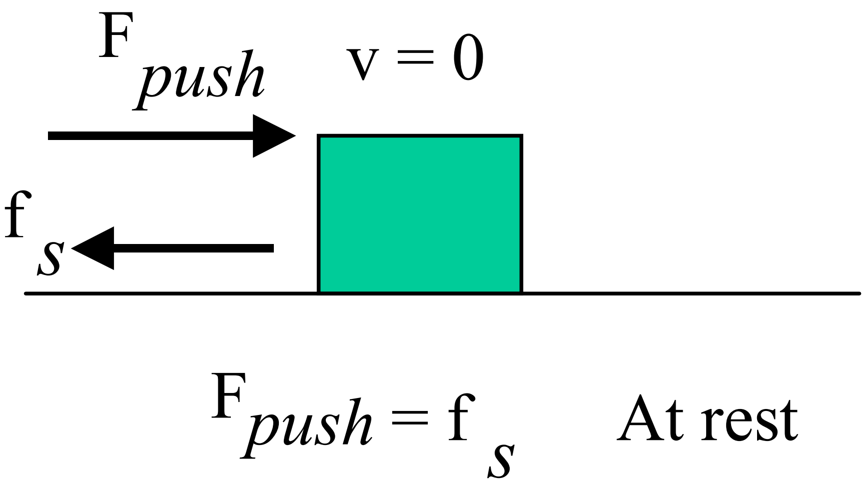
3.4 friction force – in detail

- There are 2 kinds of friction forces:
  - Static friction force (f_s)
  - Kinetic friction force (f_k)

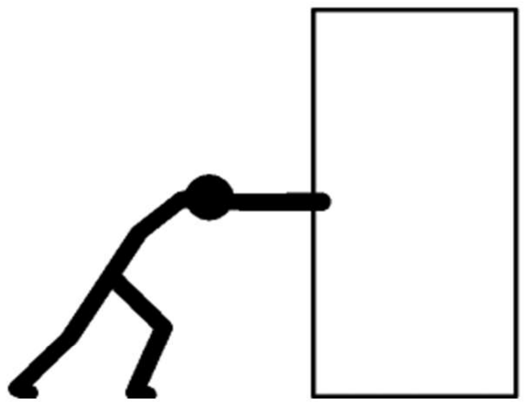


If a block is at rest (Not Movement) , no forces with horizontal components are applied to the block, then there is no static friction force.

3.4 friction force



Pushing heavy object



Apply an external horizontal force, F_{push} to the block, the block remains stationary(not moving).

Conclude that an equal and opposite force acts on the block to prevent it from moving . This is the static friction force, f_s.

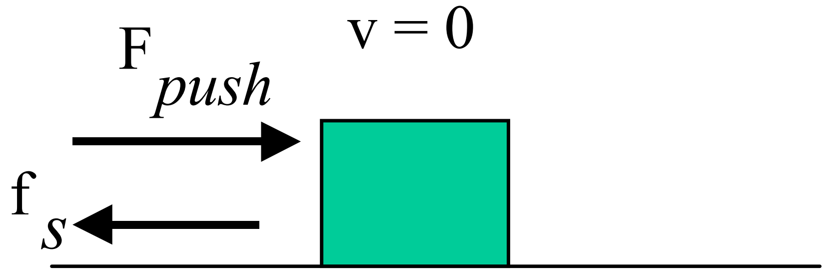
3.4 friction force

The static friction force is not a fixed value but it always equal to the applied force.

As long as the block is not moving,

$$F_{push} = f_s$$

3.4 friction force



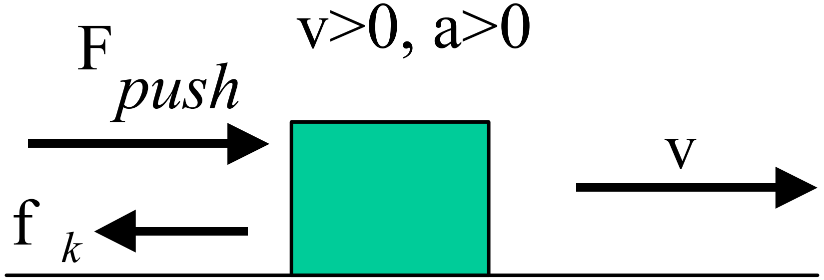
$F_{push} = f_{s_{max}}$ At rest

Static friction at its maximum

If we increased the horizontal applied force, F_{push} the static friction force will increase by the same amount until it reached its maximum value, $f_{s_{max}}$

$$f_{s_{max}} = \mu_s F_N$$ F_N = Weight

3.4 friction force

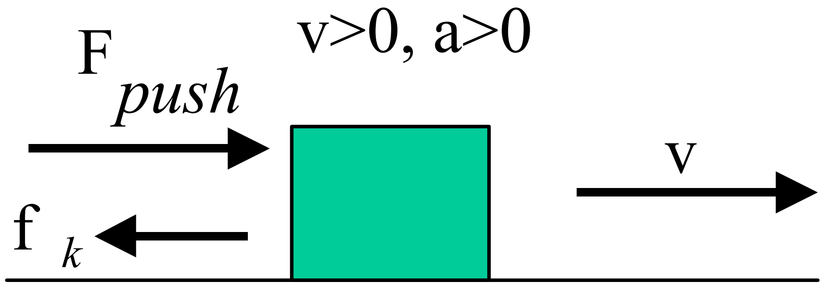


$$F_{push} > f_{s_{max}}$$

kinetic friction sets in

- If we Increase the magnitude of F_{push}, the block eventually slips, $\Rightarrow f_{smax}$.
- When F_{push} exceeds f_{smax} the block moves and accelerate.

3.4 friction force

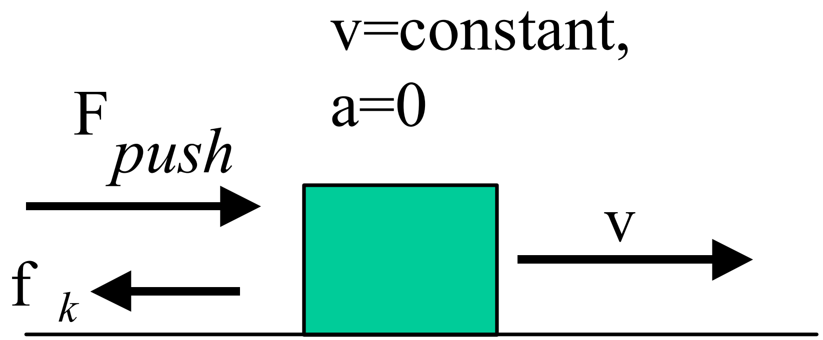


$$F_{push} > f_{s\,\max}$$

kinetic friction sets in

- The retarding force $\Rightarrow$ kinetic friction force, f_k
- The value of f_k is smaller than the maximum value of f_s .

3.4 friction force



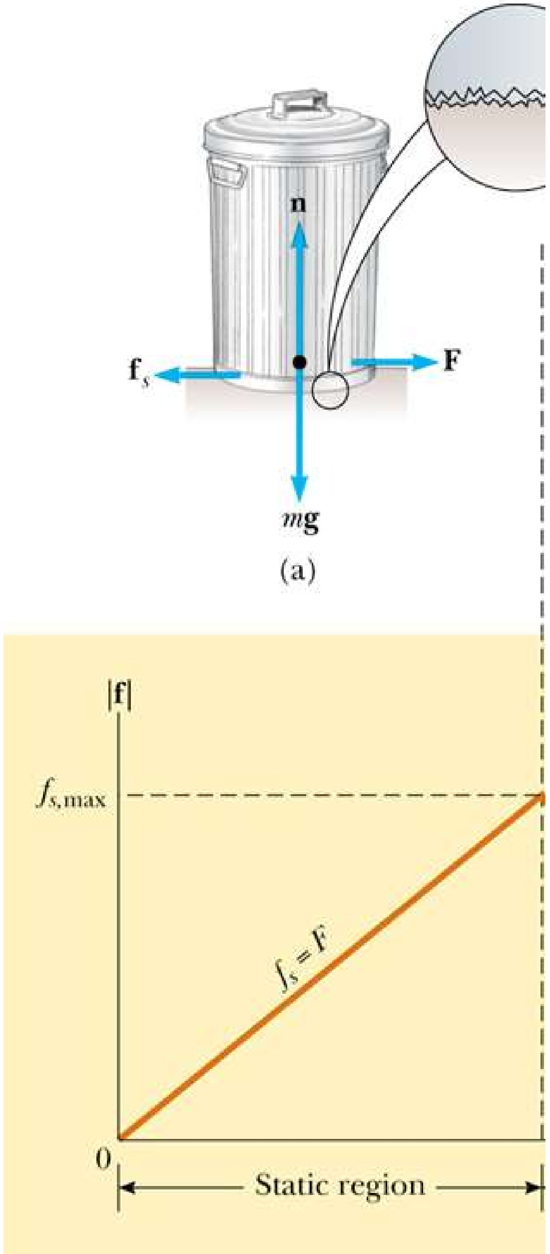
$$F_{push} = f_k$$

pushing force reduced

- If F is removed, the friction force acting to the left, accelerate the block in the negative x direction and eventually bring it to rest !

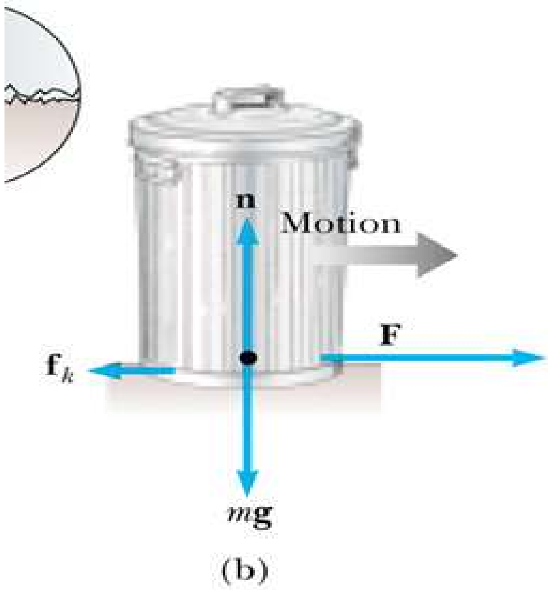
3.4 friction force

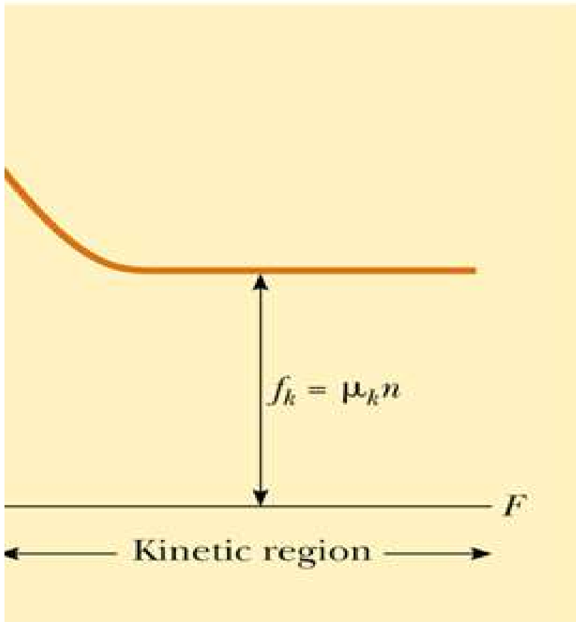
- Characteristics of Static Friction Force
  - Static friction acts to keep the object from moving
  - If F increases, so does f_s
  - If F decreases, so does f_s
  - $f_s \leq \mu F_N$



3.4 friction force

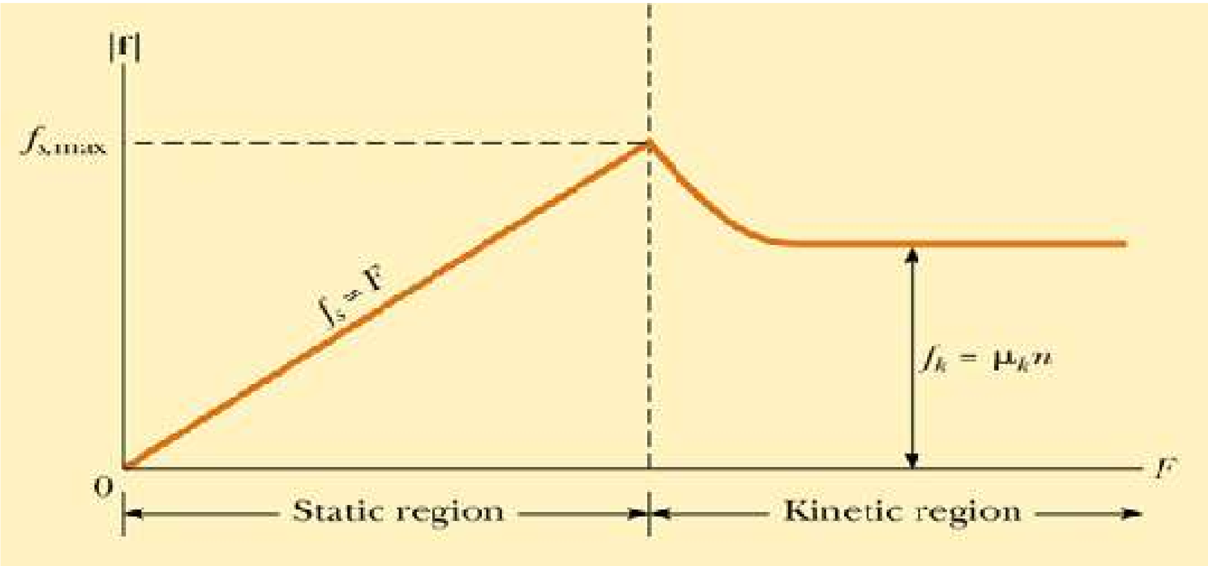
- Characteristic of Kinematic Friction Force
  - The force of kinetic friction acts when the object is in motion
  - $f_k = \mu\, F_N$





3.4 friction force

- Overall of Static friction force and kinematic friction force
  - Friction is proportional to the normal force
  - The force of static friction is generally greater than the force of kinetic friction



3.4 friction force

- The coefficient of friction
  - depends on the surfaces in contact
  - The direction of the frictional force is opposite the direction of motion (direction of applied force)
  - The coefficients of friction are nearly independent of the area of contact
  - The coefficient of friction is dimensionless and determined experimentally

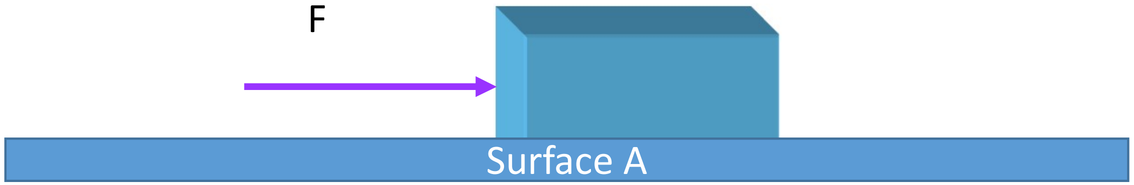
μ_s - Coefficient of Static Friction

μ_k - Coefficient of Kinematic Friction

3.4 friction force

surface-on-surface	μ_s	μ_k	
hook velcro-on-fuzzy velcro	>6.0	>5.9	
avg tire-on-dry pavement	0.9	0.8	Sticky
grooved tire-on-wet pavement	0.8	0.7	
glass-on-glass	0.9	0.4	
metal-on-metal (dry)	0.6	0.4	
smooth tire-on-wet pavement	0.5	0.4	
metal-on-metal (lubricated)	0.1	0.05	
steel-on-ice	0.1	0.05	
steel-on-Teflon	0.05	0.05	Slippery

3.4 friction force



- Example

The coefficient of static and kinetic friction between a 3.0 kg box and Surface A are 0.40 and 0.30 respectively. What is the net force on the box when each of the following horizontal force is applied to the box?

a.) 5.0N

b.) 15.0 N

3.4 friction force

- Solution

a.)

$$\mu_s = 0.40, \mu_k = 0.30, F_{push} = 5.0N, m = 3kg$$

$$\sum F_y = 0$$

y-axis force is equilibrium

The maximum static friction force,

$$\begin{aligned} f_s &= \mu_s F_N \\ &= \mu_s mg \\ &= 0.4(3)(9.8) \\ &= 11.76N \end{aligned}$$

Since the applied force is smaller than the maximum static friction force ($F_{push} < f_s$)
So, the object remains at rest .

3.4 friction force

- Solution

b.) $$\mu_s = 0.40, \mu_k = 0.30, F_{push} = 15.0N, m = 3kg$$

$$\sum F_y = 0$$

y-axis force is equilibrium

The maximum static friction force,

$$\begin{aligned} f_s &= \mu_s N \\ &= \mu_s mg \\ &= 0.4(3)(9.8) \\ &= 11.76N \end{aligned}$$

Since the applied force is more than the maximum static friction force ($F_{push} > f_s$)
So, the object is in motion with a acceleration.

3.4 friction force

Kinematic friction force, f_k

$$f_k = \mu_k mg$$
$$= 0.3(3)(9.8)$$
$$= 8.82N$$

$$\sum F_x = F_{push} - f_k$$
$$= 15 - 8.82$$
$$= 6.18N$$

the box will accelerate at a rate of

$$\sum F_x = ma$$
$$ma = F_{push} - f_k$$
$$(3)a = 6.18N$$
$$a = 2.06ms^{-2}$$

3.4 friction force

- Example

A person exerts a horizontal force of 267 N in attempting to push a freezer across a room, but the freezer does not move. What is the static friction force that the floor exerts on the freezer?

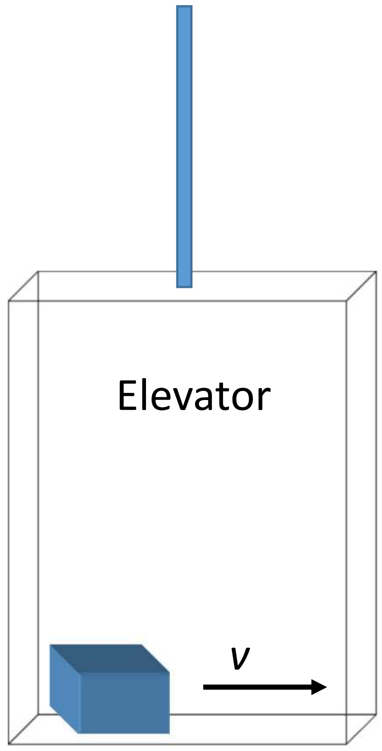
Solution

267 N, since the freezer does not move, so the applied force is equal to the static friction force.

3.4 friction force

- Example

A 6.0 kg box is sliding across the horizontal floor of an elevator. The coefficient of kinetic friction between the box and the floor is 0.360. Determine the kinetic frictional force that acts on the box when the elevator is,



a.) stationary

b.) accelerating upward with an acceleration whose magnitude is 1.2 ms^{-2} .

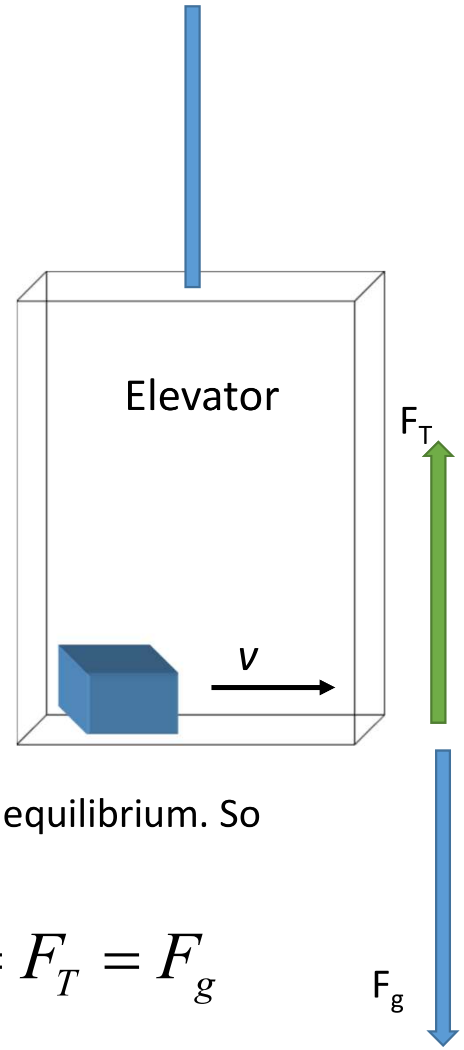
c.) accelerating downward with an acceleration whose magnitude is 1.2 ms^{-2}.

3.4 friction force

a.)

kinetic frictional force,

$$\begin{aligned} f_k &= \mu_k N \\ &= \mu_k (mg) \\ &= 0.36(6)(9.8) \\ &= 21.2N \end{aligned}$$



F_T and F_g are equilibrium. So ,

$$\sum F_x = F_T = F_g$$

3.4 friction force

b.) $f_k = \mu_k N$

Elevator move upward

$$F_T = m(a+g)$$
$$= 6(1.2+9.8)$$
$$= 66.0N$$
$$= N$$

Kinetic frictional force,

$$f_k = \mu_k N$$
$$= (0.36)(66.0)$$
$$= 23.8N$$

3.4 friction force

b.) $f_k = \mu_k N$

Elevator move upward

$$
\begin{aligned}
F_T &= m(g-a) \\
&= 6(9.8-1.2) \\
&= 51.6N \\
&= N
\end{aligned}
$$

Kinetic frictional force,

$$
\begin{aligned}
f_k &= \mu_k N \\
&= (0.36)(51.6) \\
&= 18.6N
\end{aligned}
$$


THANK YOU