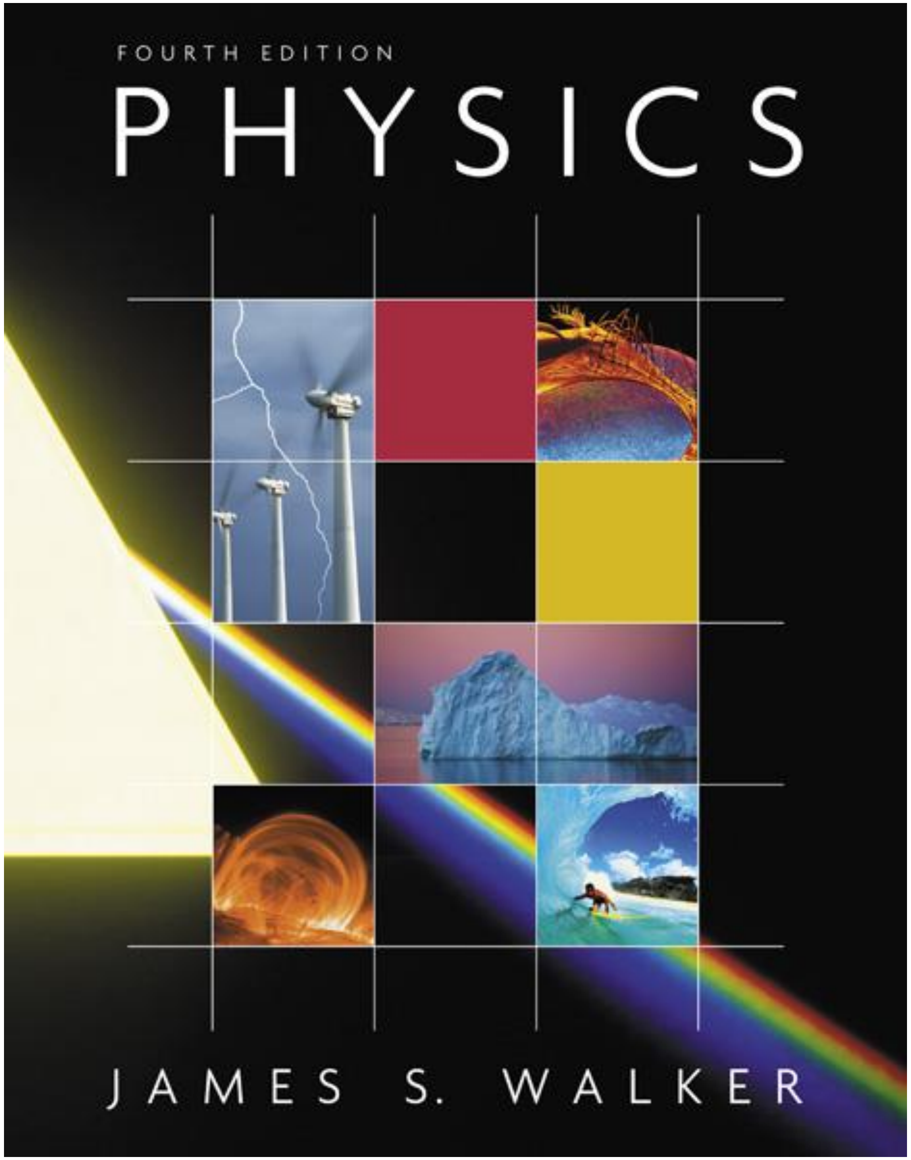


Lecture Outline

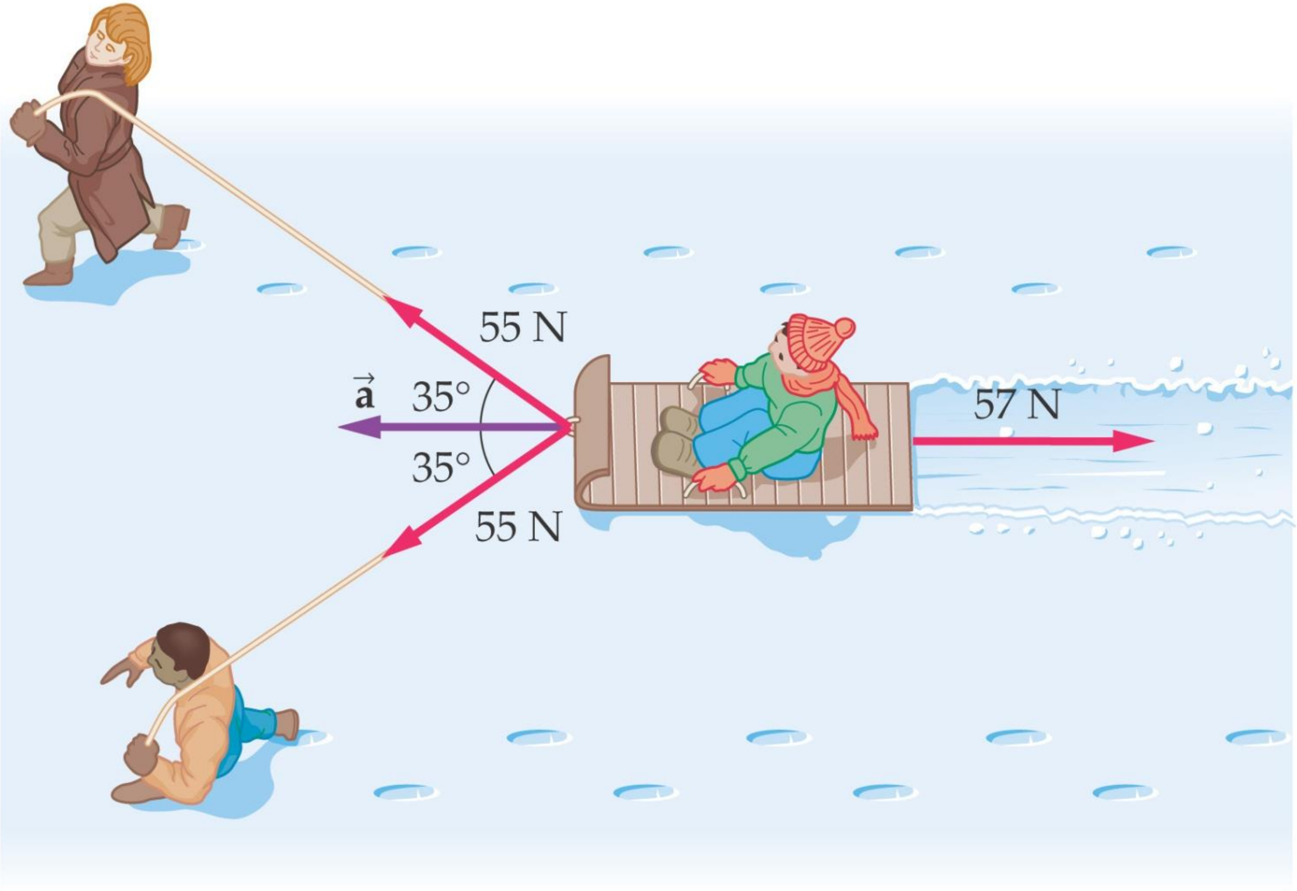
Chapter 5

***Physics*, 4th Edition**

James S. Walker

Chapter 5

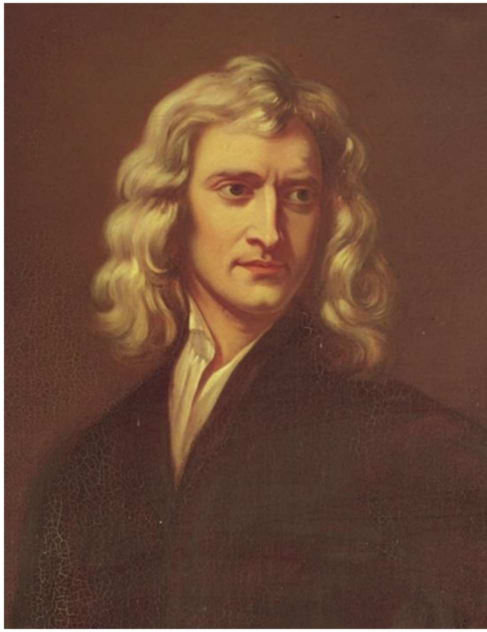
Newton's Laws of Motion



- ✓ This chapter will introduce Newton's three laws of motion and the law of gravity
- ✓ These laws are considered among the greatest achievements of the human mind

Sir Isaac Newton

- 1642 – 1727
- Formulated basic concepts and laws of mechanics
- Universal Gravitation
- Calculus
- Light and optics



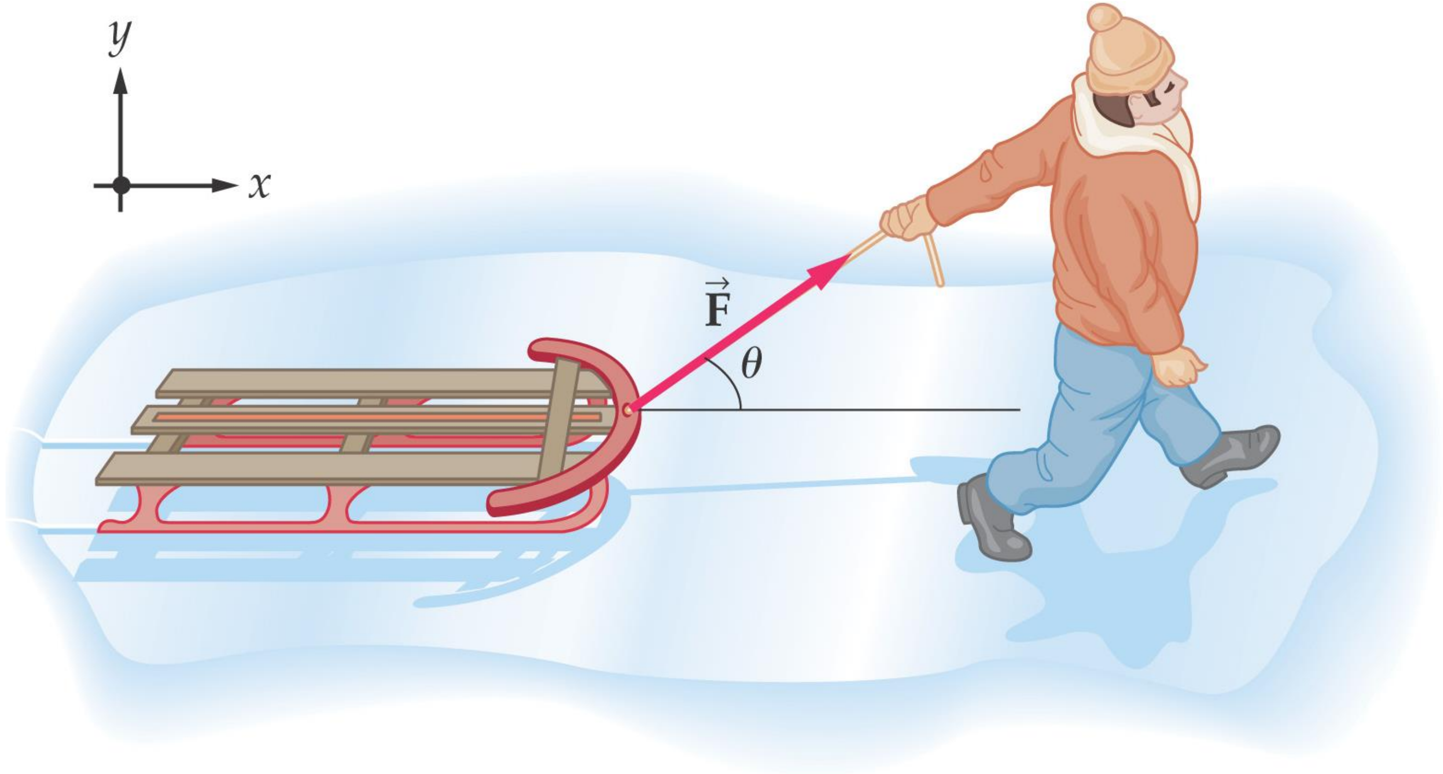
Units of Chapter 5

- Force and Mass
- Newton's First Law of Motion
- Newton's Second Law of Motion
- Newton's Third Law of Motion
- Weight
- Normal Forces

5-1-- Force and Mass

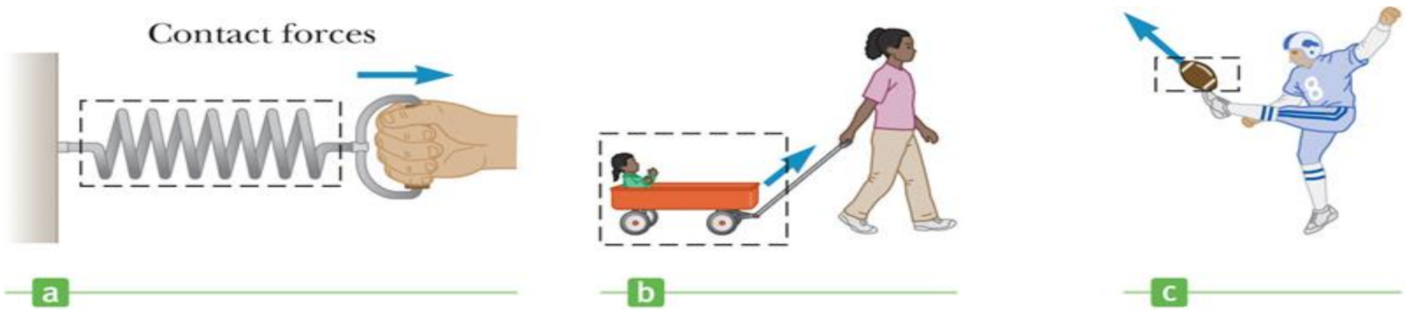
Force: push or pull

Force is a **vector** – it has magnitude and direction

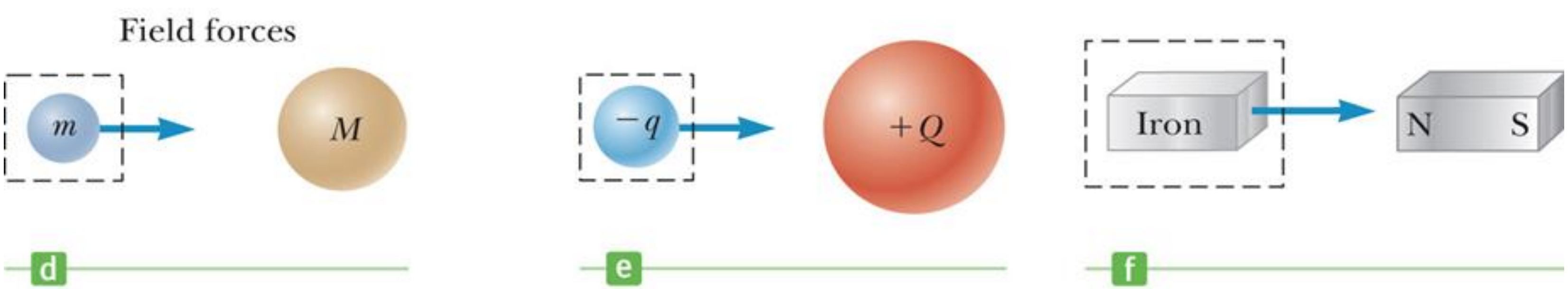


Forces

- May be a **contact force** or a **field force**
  - Contact forces result from physical contact between two objects



  - Field forces act between disconnected objects (action at a distance)



External and Internal Forces

- External force
  - Any force that results from the interaction between the object and its environment

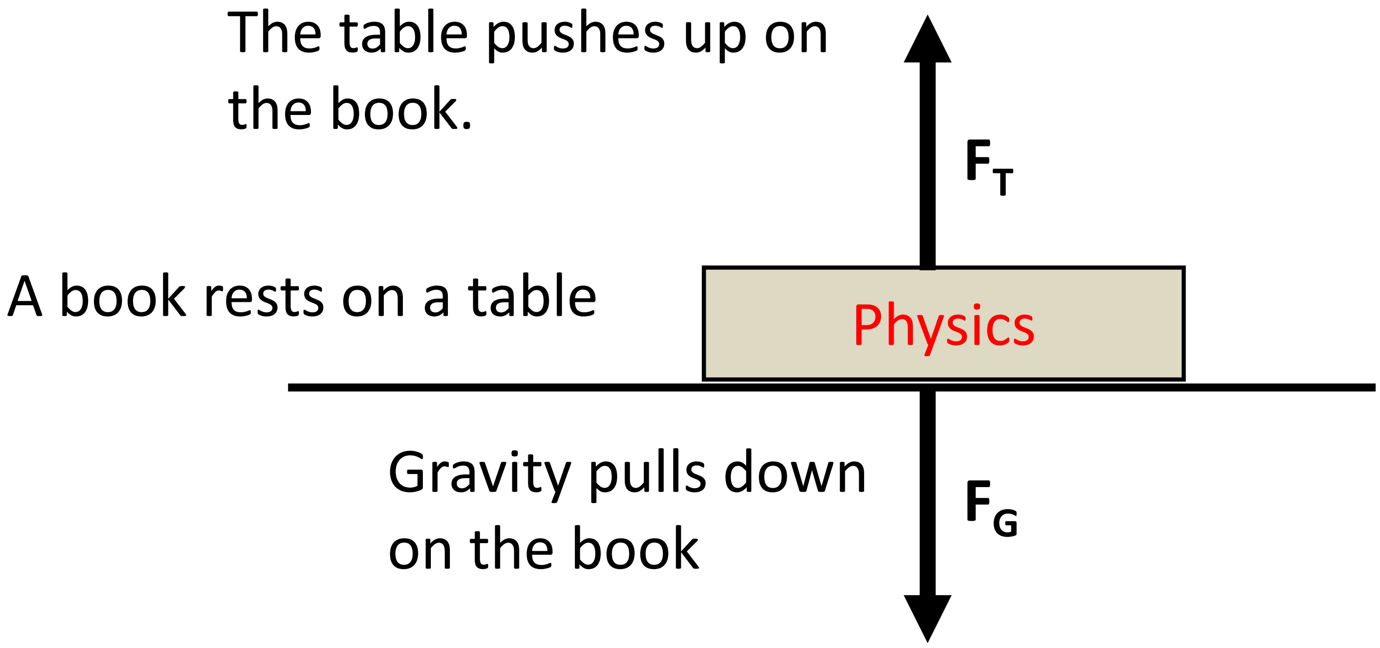
- Internal forces
  - Forces that originate within the object itself
  - They cannot change the object’s velocity

Newton's First Law

- **An object moves with a velocity that is constant (in magnitude and direction), unless acted on by a nonzero net force**
  - The net force is defined as the vector sum of all the external forces exerted on the object
- In other words:
  - In the absence of a net external force, an object at rest remains at rest, and an object in motion continues moving at a constant velocity (same speed in the same direction)

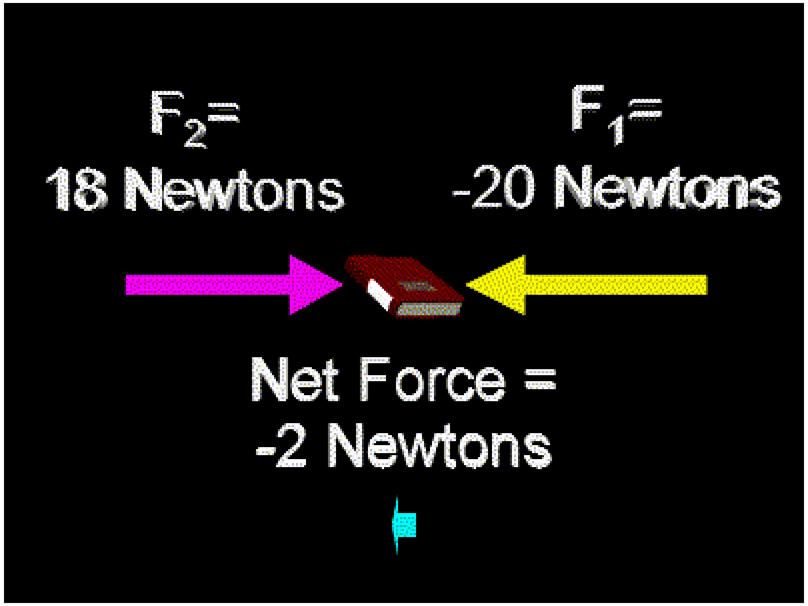
➢ the object is said to be in equilibrium.

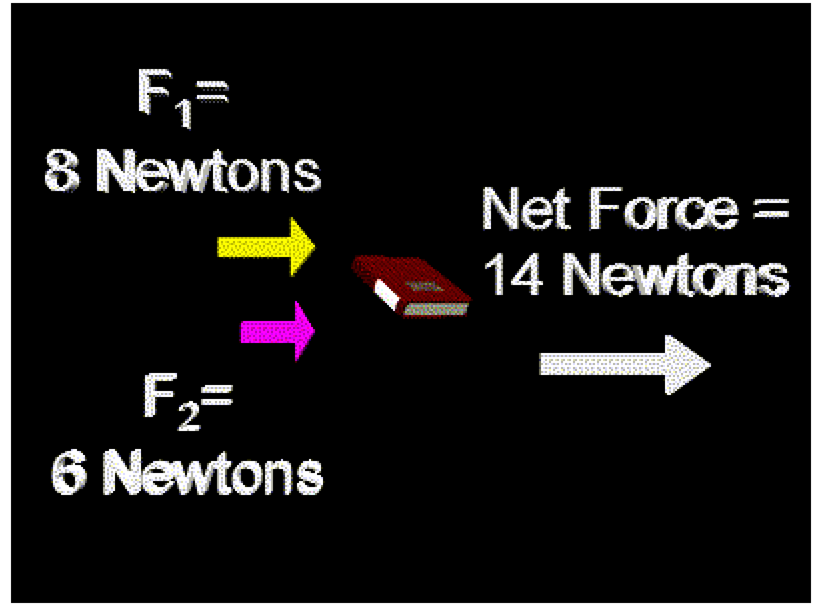
What is Zero Net Force?

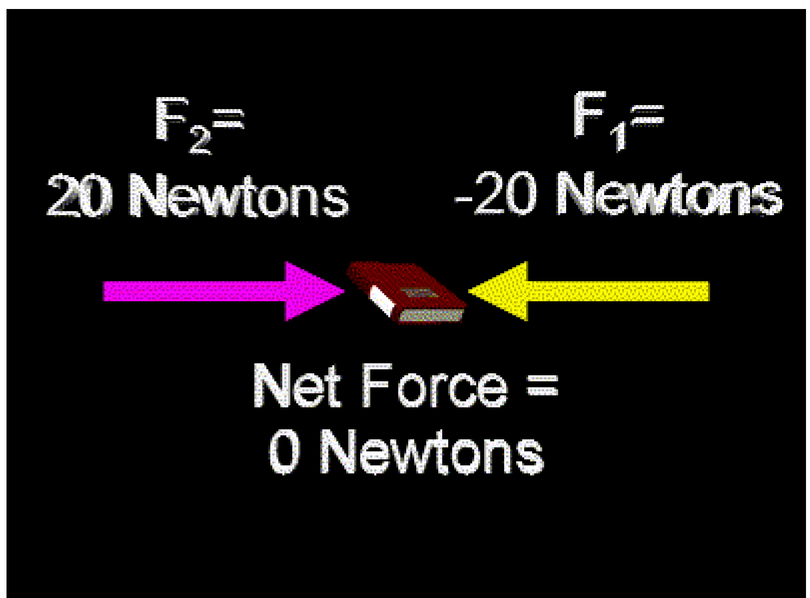


Even though there are forces on the book, they are **balanced.** Therefore, there is no net force on the book.

$$\Sigma F = 0$$

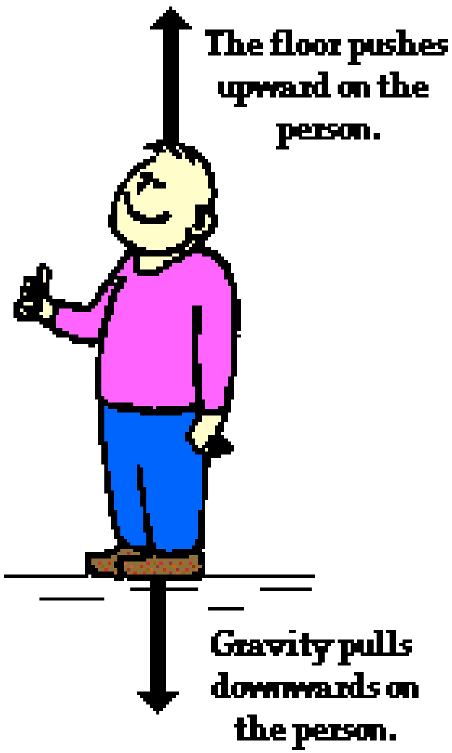

F_2=
18 Newtons
F_1=
-20 Newtons
Net Force =
-2 Newtons


F_1=
8 Newtons
F_2=
6 Newtons
Net Force =
14 Newtons

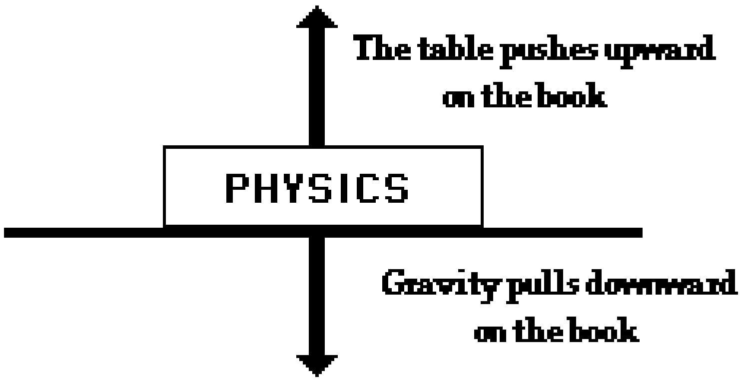

F_2=
20 Newtons
F_1=
-20 Newtons
Net Force =
0 Newtons

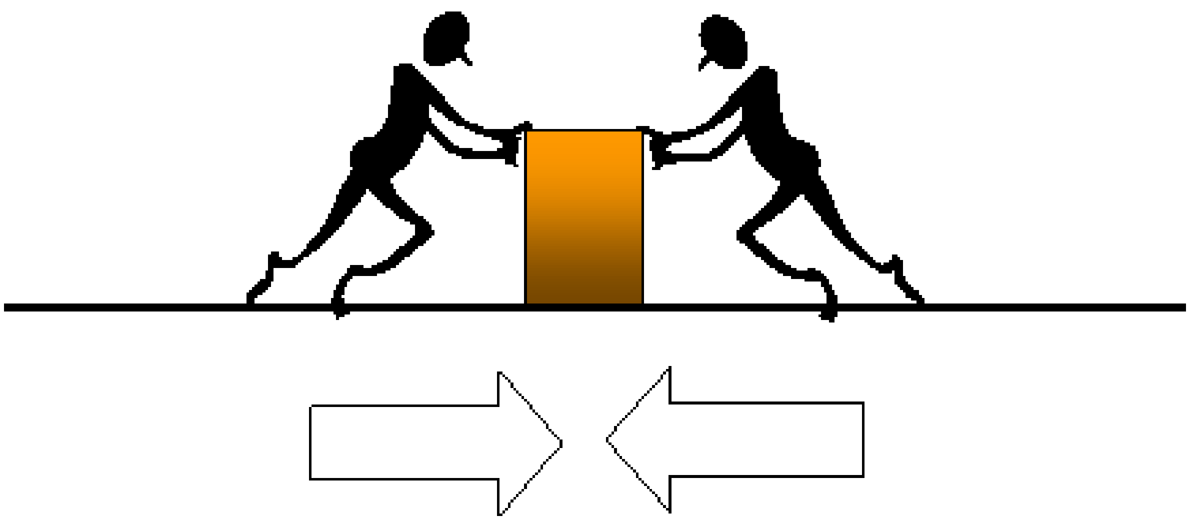
Examples of Balanced Forces

The forces on the person are balanced.



The forces on the book are balanced.





1^{st} Law

if no **net force** acts on a body ($F_{net}=0$), the body's velocity cannot change (velocity=constant), that is, the body cannot accelerate (acceleration on an object is zero) This means:

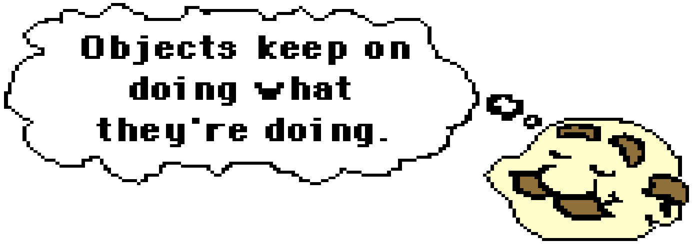
- it cannot turn,
- it cannot speed up,
- it cannot slow down.

According to Newton's first law

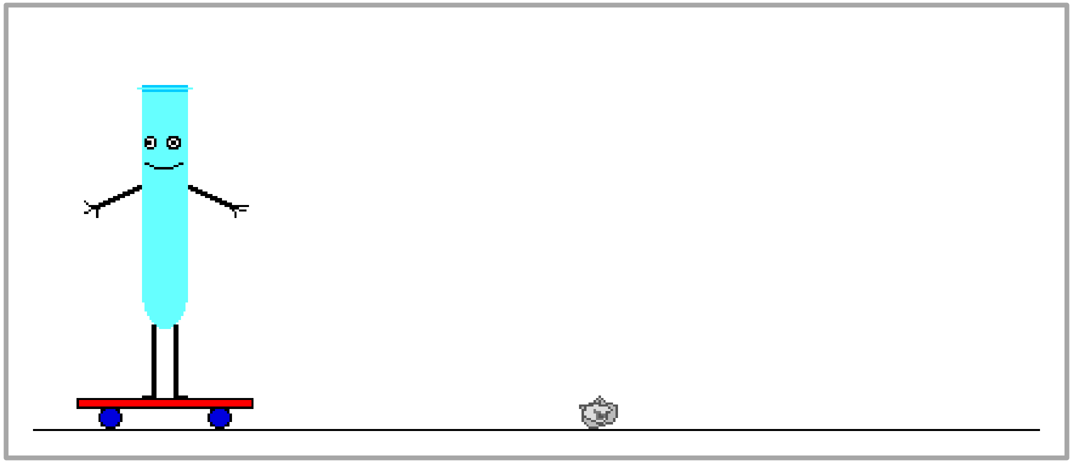
(law of inertia):

What is inertia?

Inertia is the tendency of an object to resist changes in its velocity: whether in motion or motionless.



Let's study the "skater" to better understand inertia

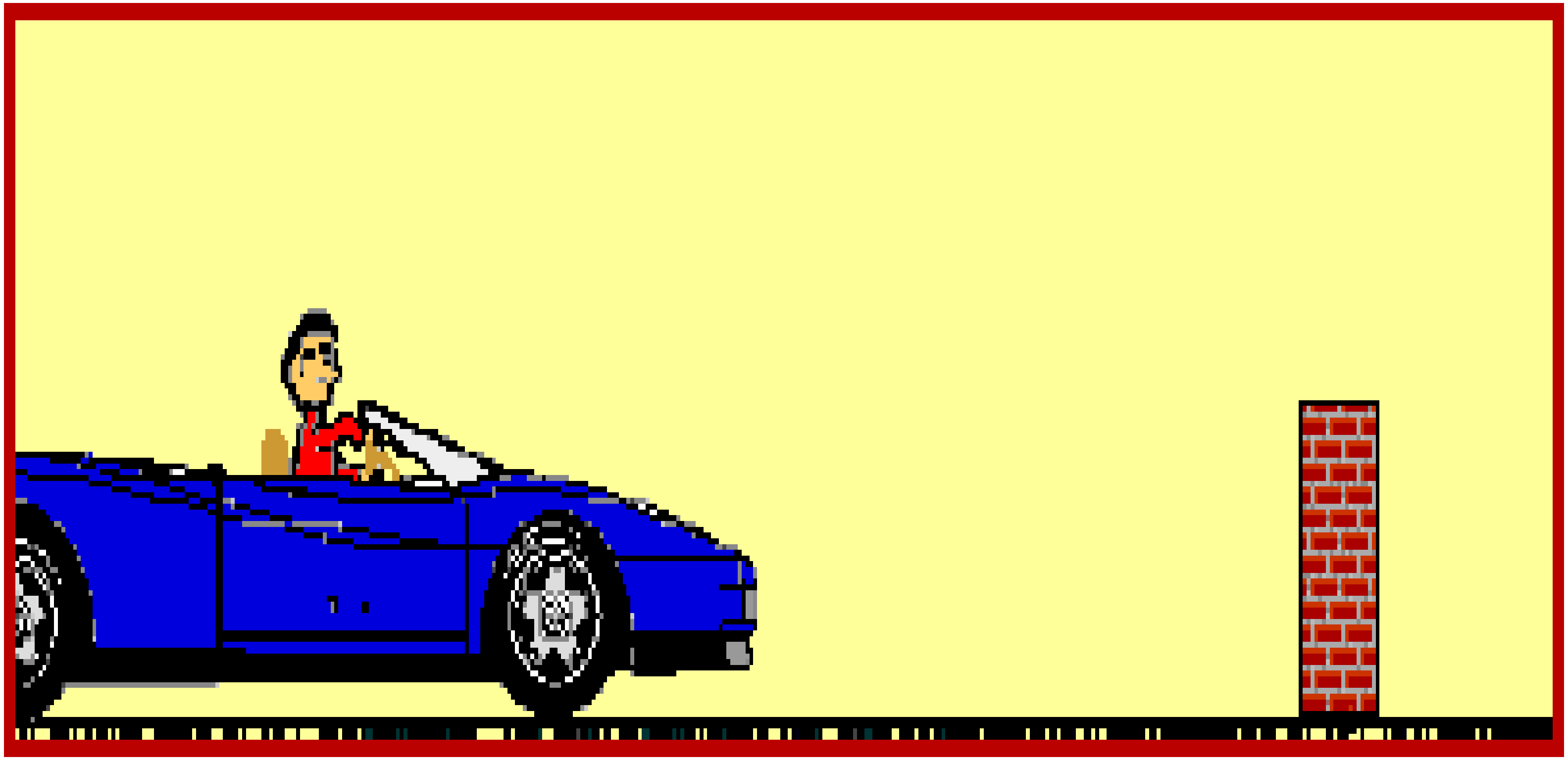


What is the motion in this picture?

What is the unbalanced force in this picture?

What happened to the skater in this picture?

This law is the same reason why you should always wear your seatbelt



5-2- Newton's First Law of Motion

In order to change the velocity of an object – **magnitude** or **direction** **– a net force is required.**

An inertial reference frame is one in which the first law is true. **Accelerating reference frames** are not inertial, e.g., earth is approximately an inertial frame of reference

Force and Mass

- **Mass** is the measure of how hard it is to change an object's velocity.
- **Mass** can also be thought of as a measure of the quantity of matter in an object.

TABLE 5–1
Typical Masses in Kilograms (kg)

Earth	5.97×10^{24}
Space Shuttle	2,000,000
Blue whale (largest animal on Earth)	178,000
Whale shark (largest fish)	18,000
Elephant (largest land animal)	5400
Automobile	1200
Human (adult)	70
Gallon of milk	3.6
Quart of milk	0.9
Baseball	0.145
Honeybee	0.00015
Bacterium	10^{-15}

Difference between Mass and Weight

Mass

1. Is always constant at any place and time
2. Is measured in kilograms in SI unit
3. Is measured using balance
4. Can never be zero
5. Is an intrinsic property of a body and is independent of any external factor

Weight

1. Depends on gravity at the place
2. Is measured in Newton not in kilograms
3. Is measured using scales
4. Can also be zero
5. Depends on
   a. Mass of the object which is attracting it
   b. Force with which it is being attracted (which depends on the distance between the two)

Unbalanced Forces

- An unbalanced force always causes a change in motion

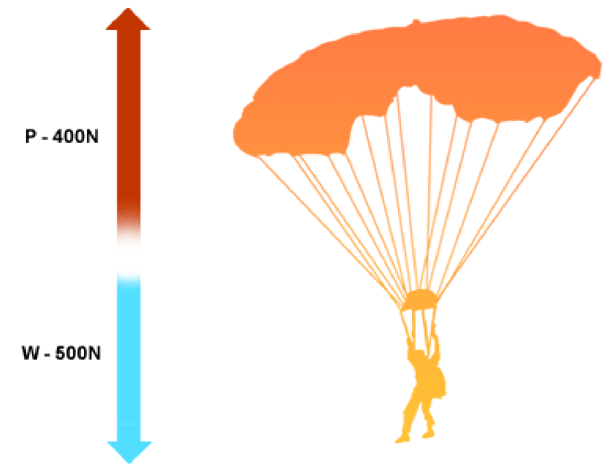
- When unbalanced forces act in opposite directions you can find the net force

  - Net force is a combination of magnitude and direction
    - Magnitude
      - The difference between the two forces

    - Direction
      - Direction of the largest force

Examples of Unbalanced Forces

Gravity is a constant force. The parachute is working against the force of gravity.



The person's finger pushes the toy truck. The truck moves in the direction of the greatest force acting on it.
Be aware that there is some force acting against the finger, but that force isn't strong enough to resist.

Examples of Unbalanced Forces

The soccer ball doesn't move until the girl provides an unbalanced force upon it.

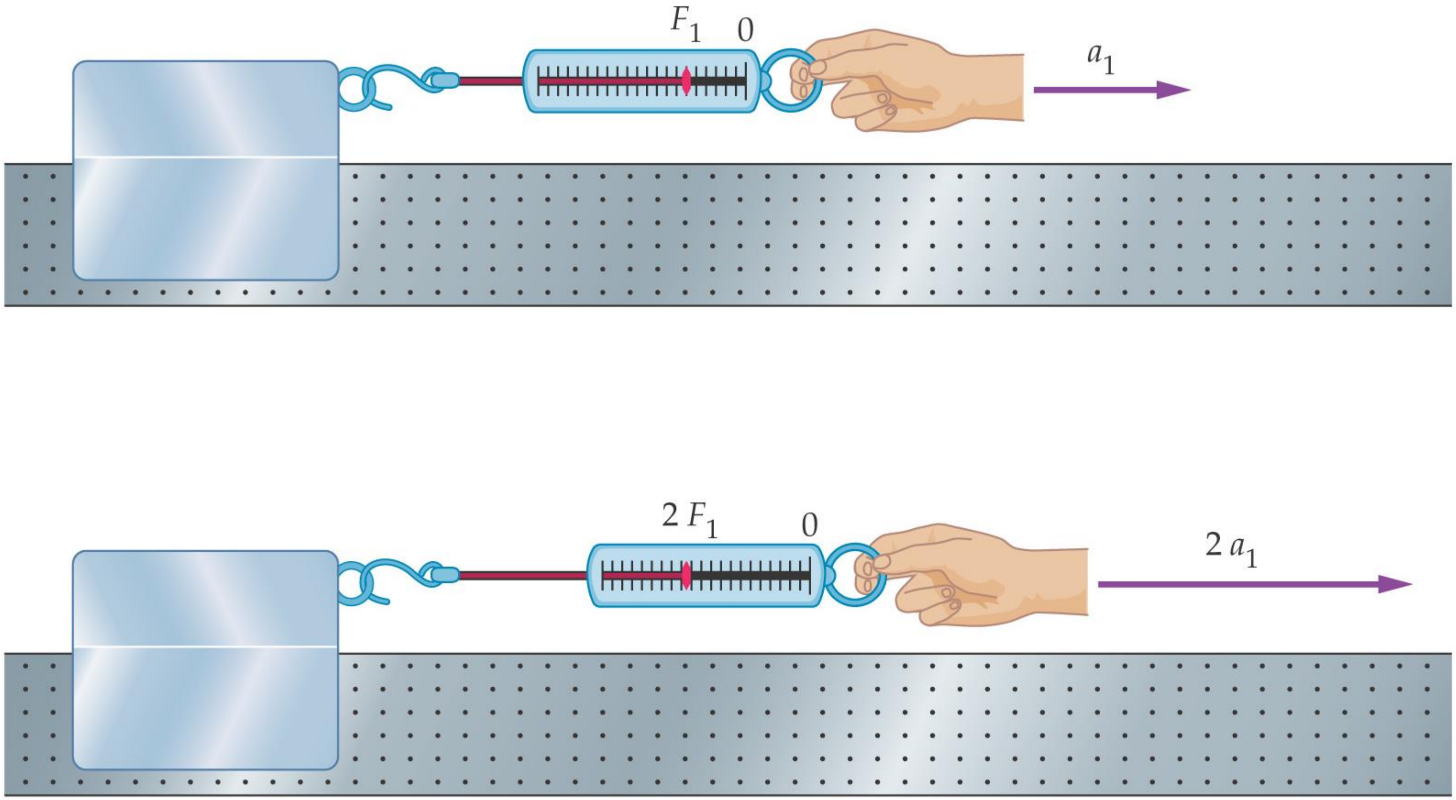
photo by burningkarma

The tug of war doesn't have the same amount of people on each side, so the forces are **not equal:** one side will be moved more than the other.

5-3- Newton's Second Law of Motion

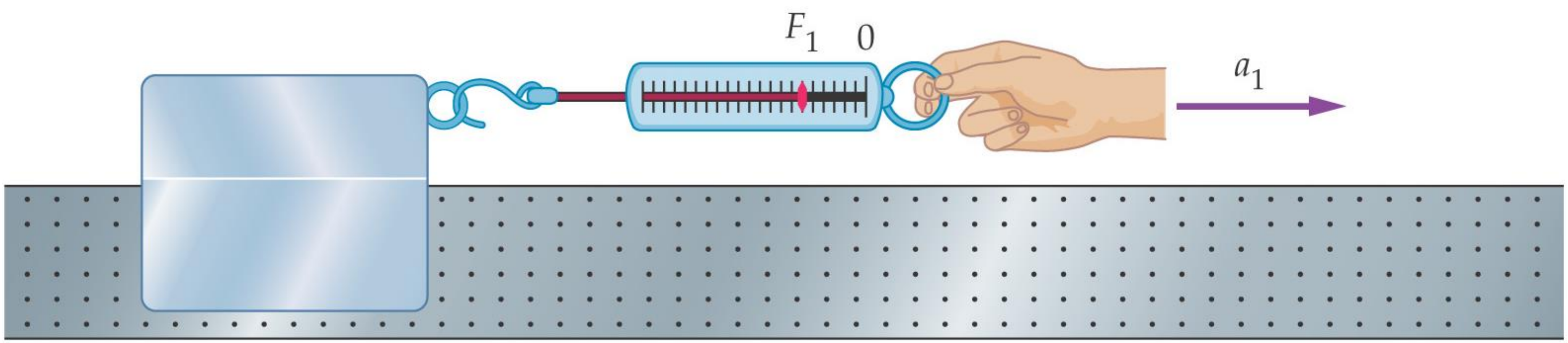
Now that we have a calibrated spring, we can do more experiments.

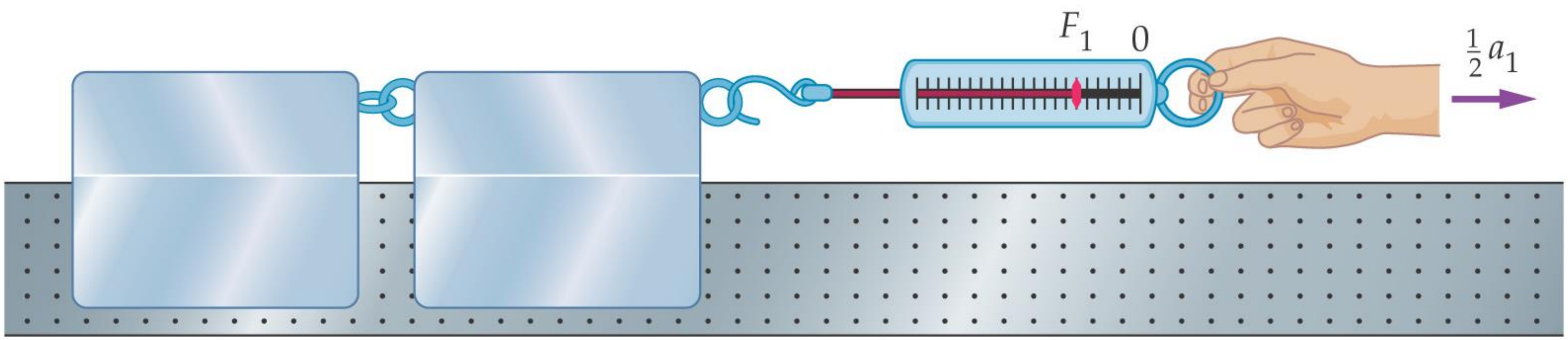
Acceleration is proportional to **force:**



5-3- Newton’s Second Law of Motion

➢ **Acceleration** is inversely proportional to mass:





5-3-- Newton's Second Law of Motion

Combining these two observations gives:

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

Or, more familiarly:

$$F = ma$$

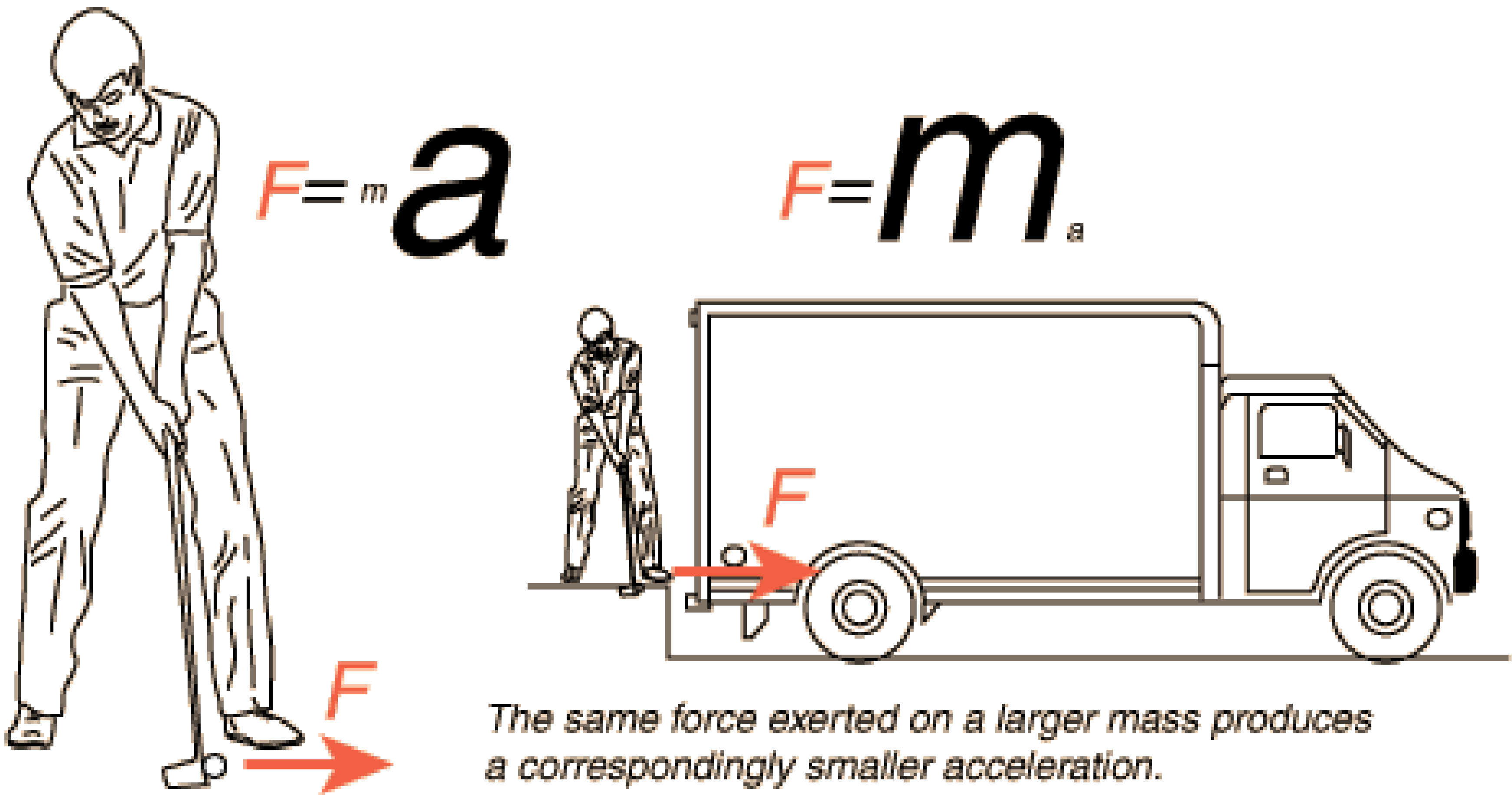
2^{nd} Law

<u>Newton's second law</u>: the net force on a body is equal to the product of the body's mass and its acceleration.

$$F_{net\ external} = ma$$

Net force on object = mass of object x acceleration

For example…


F=ma
F=ma
F
F
The same force exerted on a larger mass produces
a correspondingly smaller acceleration.

2^{nd} Law

Units of force

Newton (SI system)

$1\ N = 1\ kg\ m/s^2$

- **1 N is the force required to accelerate a 1 kg mass at a rate of 1 m/s^2**
- **Force is a vector quantity.**
- **The acceleration of an object is directly proportional to the force acting on it.**
- **The magnitude of the acceleration of an object is inversely proportional to its mass.**

According to Newton's second law

Acceleration is produced when a force acts on a mass.

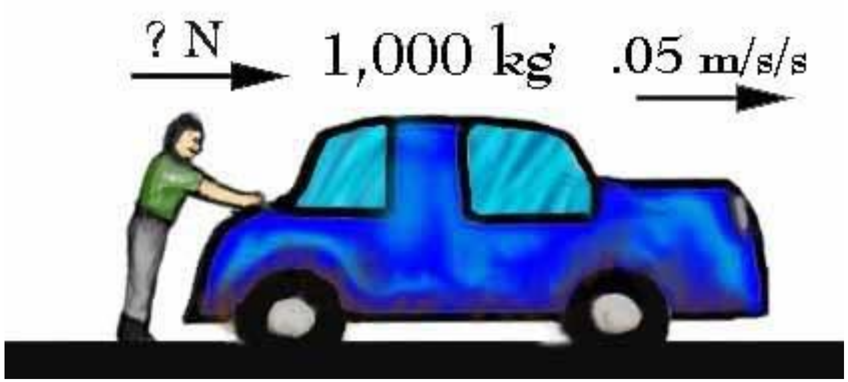
The greater the mass (of the object being accelerated) the greater the amount of force needed (to accelerate the object).

What does this mean?

- ✓ Everyone unconsciously knows the Second Law.
- ✓ Everyone knows that heavier objects require more force to move the same distance as lighter objects.

This is an example of how Newton's Second Law works

Mike's car, which weighs 1,000 kg, is out of gas. Mike is trying to push the car to a gas station, and he makes the car go 0.05 m/s/s. Using Newton's Second Law, you can compute how much force Mike is applying to the car.



Answer

$$F = 1{,}000 \times 0.05$$

= 50 Newton

5-3- Newton's Second Law of Motion

An object may have several forces acting on it; the acceleration is due to the net force:

$$\sum \vec{F} = m\vec{a} \qquad (5\text{-}1)$$

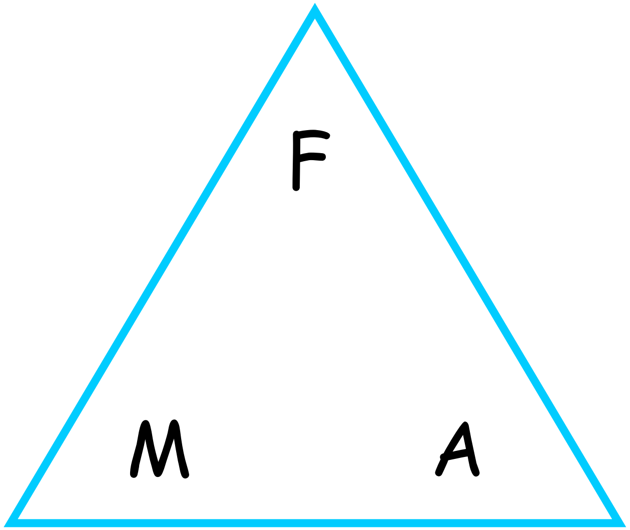
TABLE 5–2 Units of Mass, Acceleration, and Force

System of units	Mass	Acceleration	Force
SI	kilogram (kg)	m/s^2	newton (N)
cgs	gram (g)	cm/s^2	dyne (dyn)
British	slug	ft/s^2	pound (lb)

(*Note:* $1\ N = 10^5$ dyne $= 0.225$ lb.)

Force, mass and acceleration

1) A force of 1000 N is applied to push a mass of 500 kg. What is its acceleration?
2) A force of 3000 N acts on a car to make it accelerate by 1.5 m/s^2. How heavy is the car?
3) A car accelerates at a rate of 5 m/s^2. If it weighs 500 N how much driving force is the engine applying?
4) A force of 10 N is applied by a boy while lifting a 20 kg mass. How much does it accelerate by?



EXERCISE 1

The net force acting on a jaguar XK8 has a magnitude of 6800 N. If the cars acceleration is $3.8 m/s^2$, what is its mass?

Ans: - 1800 Kg

5-3- Newton's Second Law of Motion

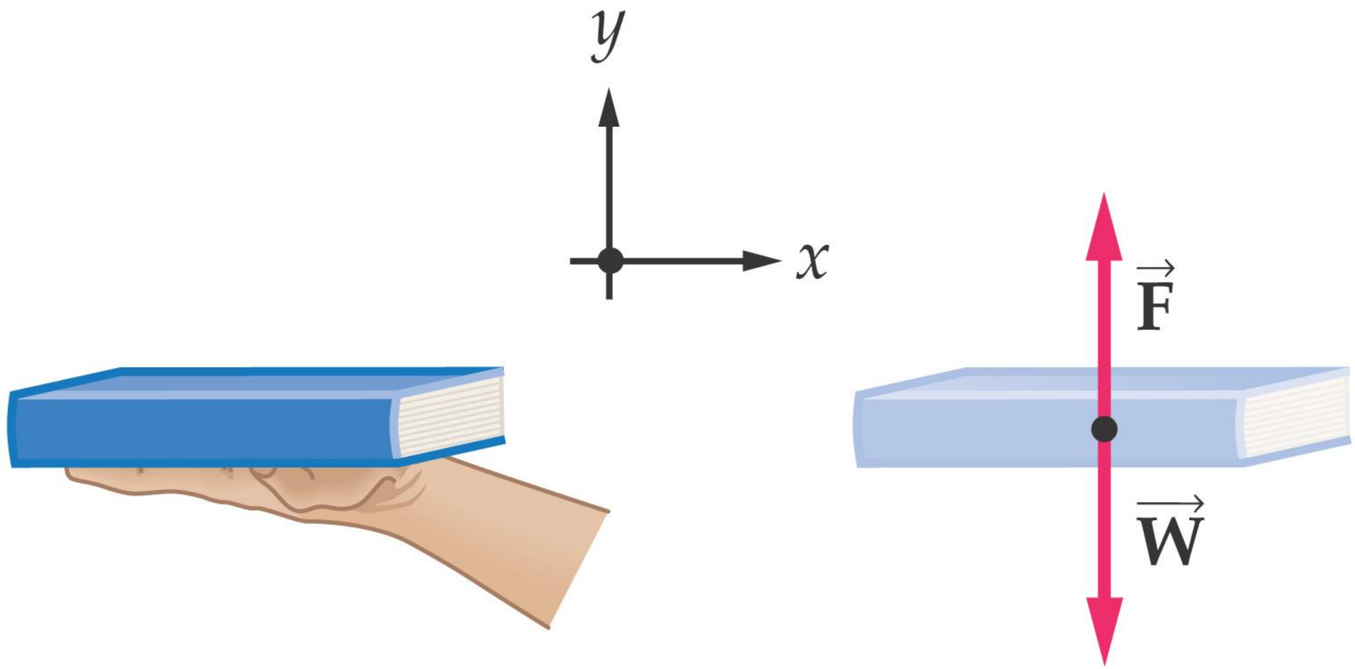
Free-body diagrams:

A free-body diagram shows every force acting on an object.

- Sketch the forces
- Isolate the object of interest
- Choose a convenient coordinate system
- Resolve the forces into components
- Apply Newton's second law to each coordinate direction

5-3- Newton’s Second Law of Motion

Example of a free-body diagram:



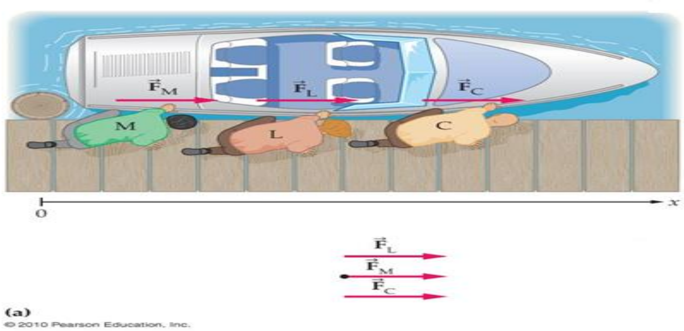
(a)
Physical picture

(b)
Free-body diagram

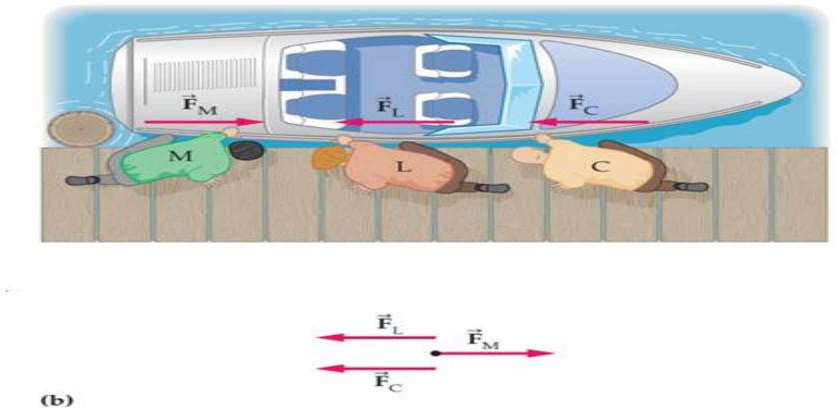
Example 5.1

Moe, Lary and Curly push on a 752 Kg boat that floats next to a dock. Each exerts an 80.5 N force parallel to the dock

(a) What is the acceleration of the boat if they all push in the same direction? Give both direction and magnitude.

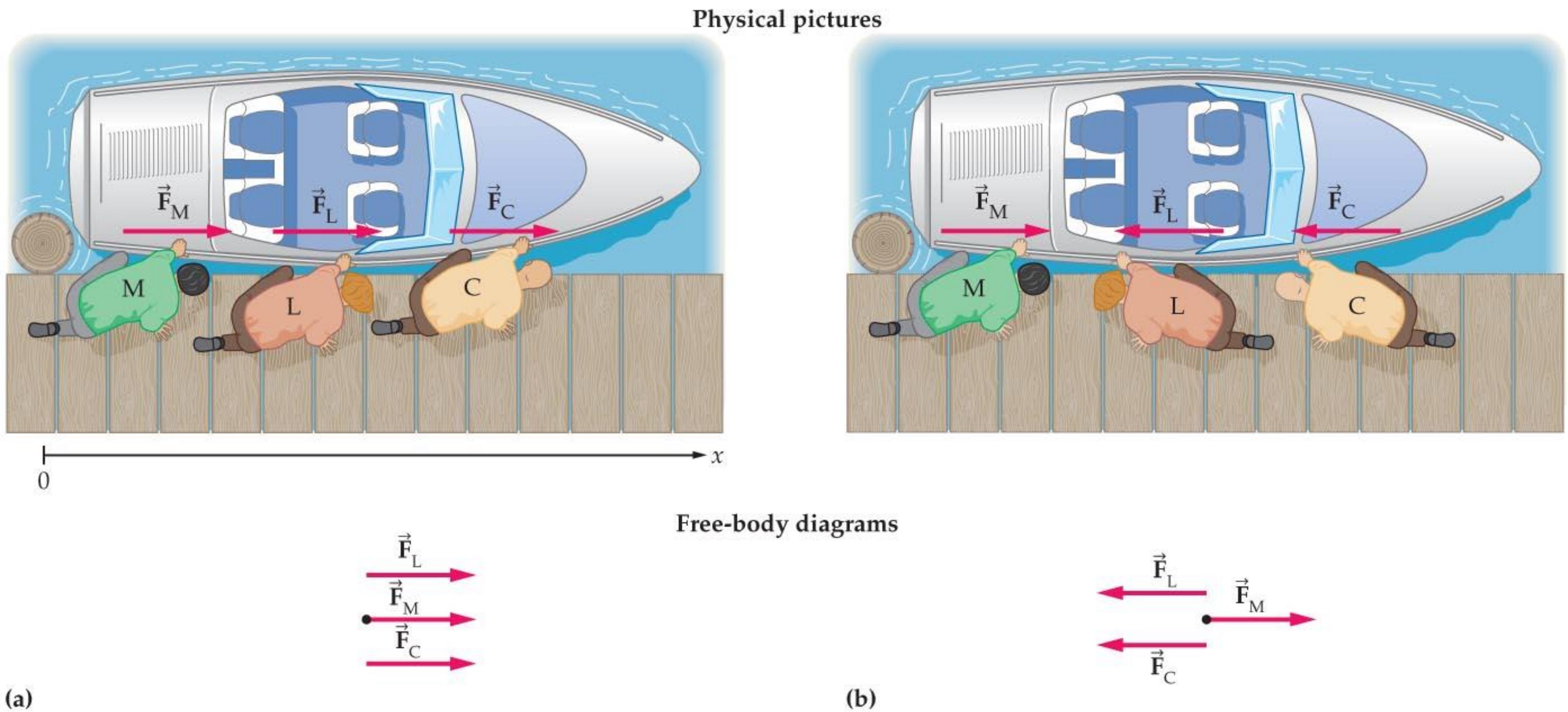


(b) What are the magnitude and direction of the boats acceleration if Larry and Curly push in the opposite direction to Moe's push?



Ans. (a) $F_x = 241.5$ N, $a_x = 0.321$ m/s^2

(b) $F_x = -80.5$ N , $a_x = -0.107$ m/s^2



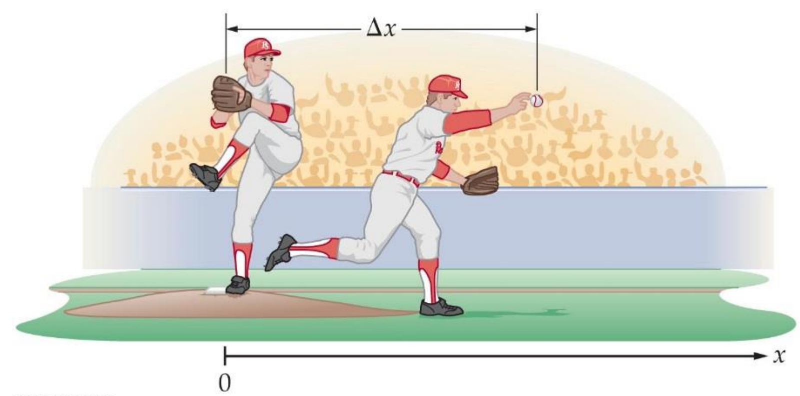
Physical pictures
$\vec{F}_M$
$\vec{F}_L$
$\vec{F}_C$
M
L
C
0
x
Free-body diagrams
(a)
(b)

Example 5.2

A pitcher throws a 0.15 Kg baseball, accelerating it from rest to a speed of about 90 mi/h. Estimate the force exerted by the pitcher on the ball. The distance over which the pitcher accelerates the ball is 2 m.

Ans.

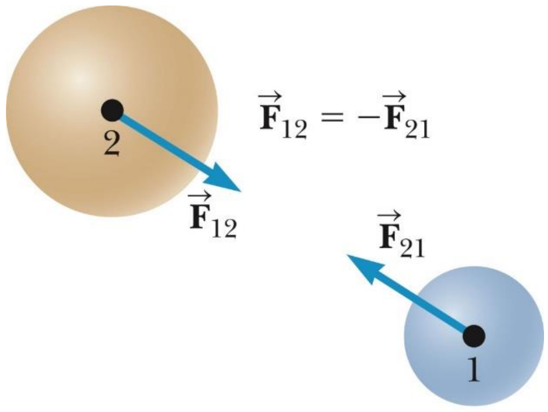
- v= 40 m/s
- a_x= 404.6 m/s^2
- F_x= 60 N



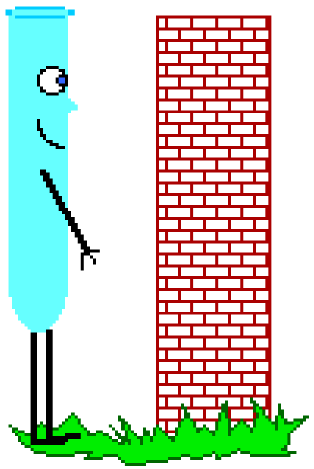
5-4- Newton's Third Law of Motion

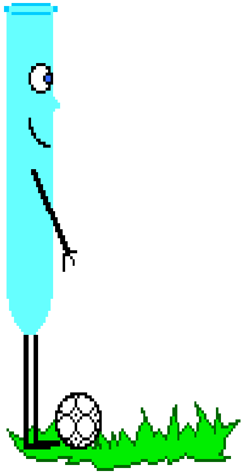
- Forces always come in pairs, acting on different objects:
- If object 1 exerts a force on object 2, then object 2 exerts a force – on object 1.
- These forces are called action-reaction pairs.

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



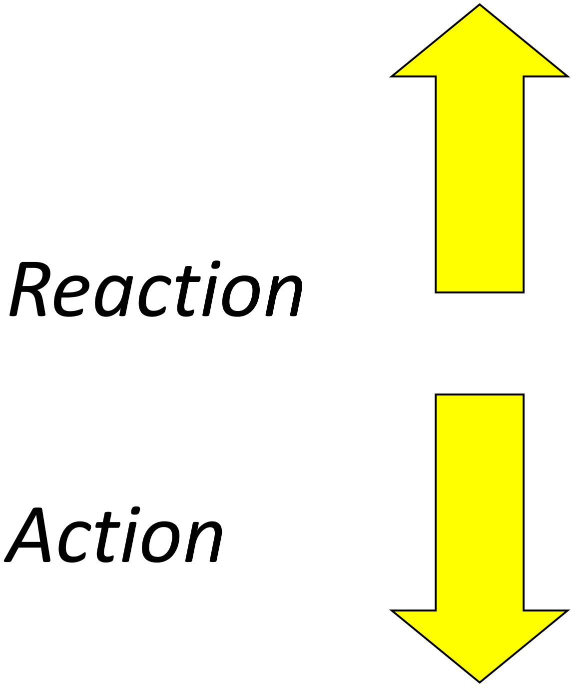
Observe what is being shown in the pictures

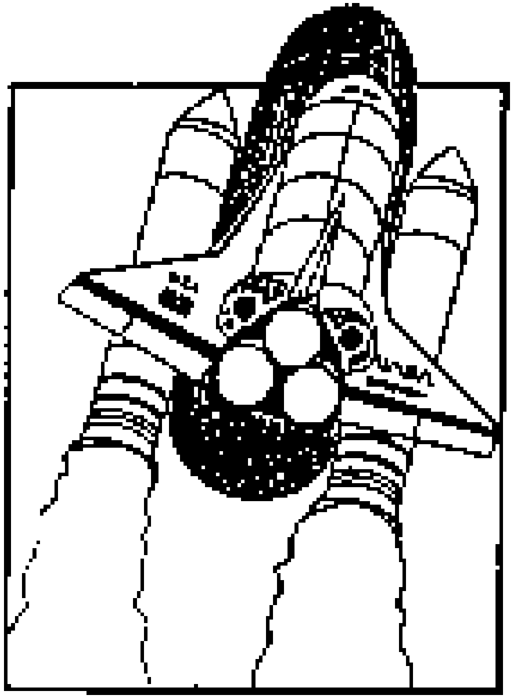




3^{rd} Law

"For every action, there is an equal and opposite reaction." Rocket launching





3^{rd} Law

The Newton's Third Law interaction is always of the form:

A pushes/pulls B

B pushes/pulls A

One of these forces is called the action force and the other one is called the reaction force - it doesn't matter which is which. For example, if:

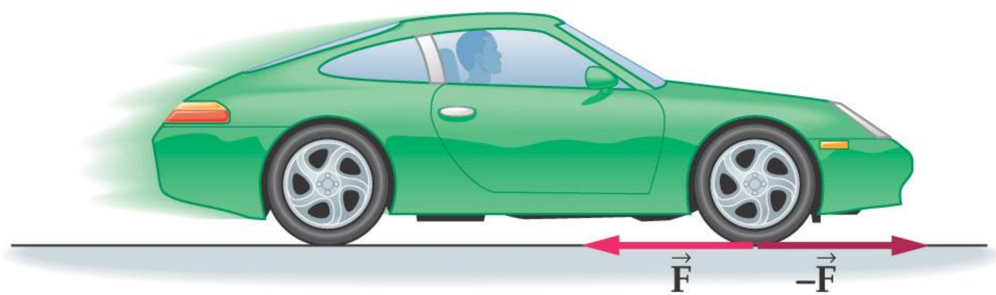
- **You push book (Action force)**

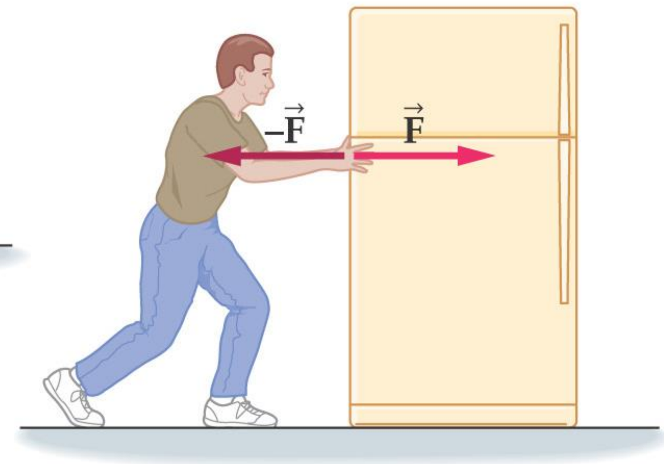
then Newton's Third Law says that:

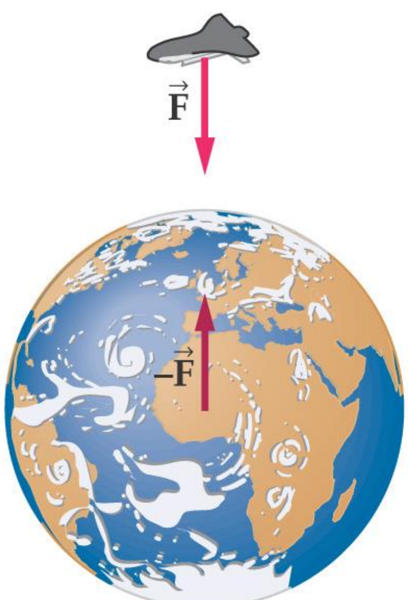
- **Book pushes you (Reaction force)**

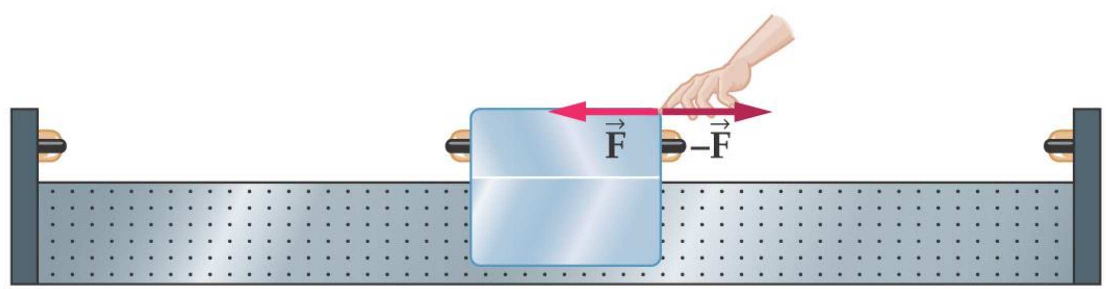
5-4- Newton’s Third Law of Motion

Some action-reaction pairs:









Example 5.3

Two groups of canoeists meet in the middle of the lake. After a brief visit, a person in canoe 1 pushes on canoe 2 with a force of 46 N to separate the canoes. If the mass of the canoe 1 and its occupants is $m_1 = 150$ kg and the mass of the canoe 2 and its occupants is $m_2 = 250$ kg: **(a)** find the acceleration the push gives to each canoe. **(b)** What is the separation of the canoes after 1.2 s of pushing?

Answers:

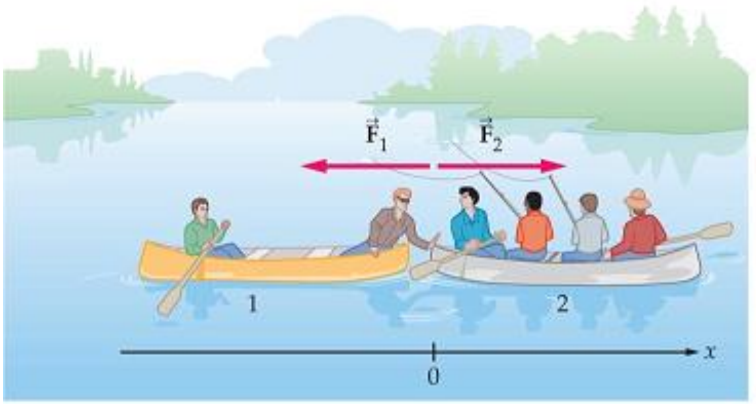
$a_{1,x} = -0.31\ m/s^2$

$a_{2,x} = 0.18\ m/s^2$

$x_2 = 0.13$ m

$x_1 = -0.22$ m

$x_2 - x_1 = 0.35$ m



Physical picture

Free-body diagrams

Problem 18

On vacation, your 1400 kg car pulls a 560 kg trailer away from a stoplight with an acceleration of 1.85 m/s^2.

(a) What is the net force exerted on the trailer?

(b) What force does the trailer exert on the car?

(c) What is the net force acting on the car?

Answers:

(a) 1036 N

(b) – 1036 N

(c) 2590 N

5-6- Weight

The weight of an object on the Earth's surface is the gravitational force exerted on it by the Earth.

Definition: Weight, *W*

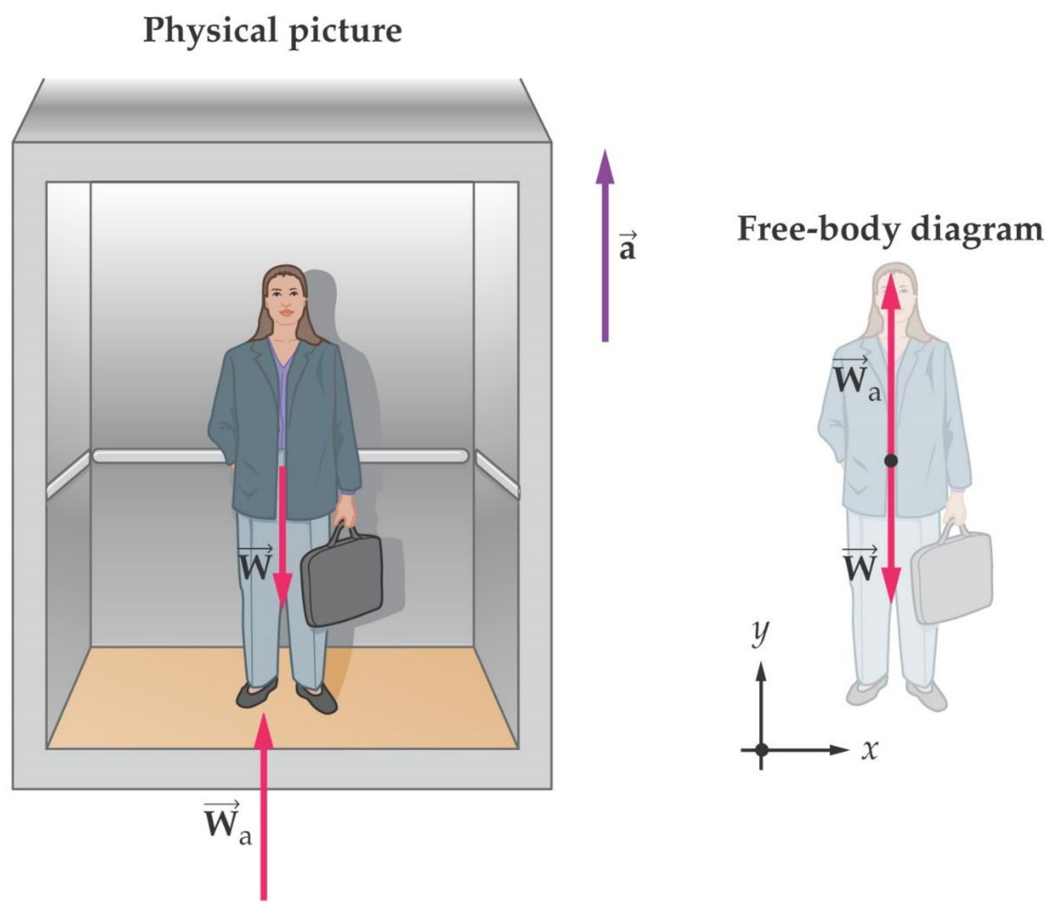
$$W = mg$$

SI unit: newton, N

5-6 Apparent Weight

Your perception of your weight is based on the contact forces between your body and your surroundings.

If your surroundings are accelerating, your apparent weight may be more or less than your actual weight.



Examples

- As part of an attempt to combine physics and biology in the same class, an instructor asks students to weigh a 5.0 kg salmon by hanging it from a fish scale attached to the ceiling of an elevator .
- What is the apparent weight of the salmon $\mathbf{W}_a$, if the elevator is at rest ?

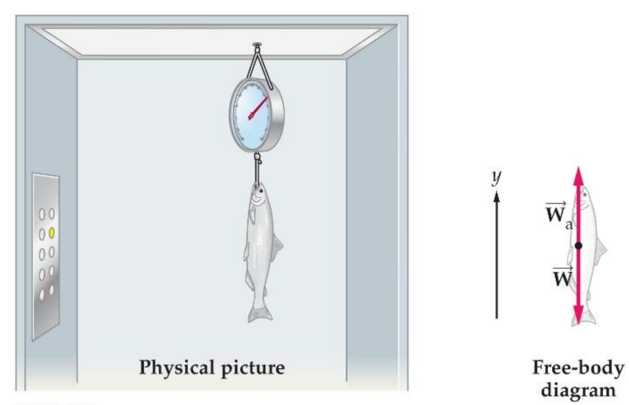
Answer: (49 N)y

- What is the apparent weight of the salmon $\mathbf{W}_a$, if the elevator moves with an upward acceleration of 2.5 m/s^2?

Answer: (62 N)y

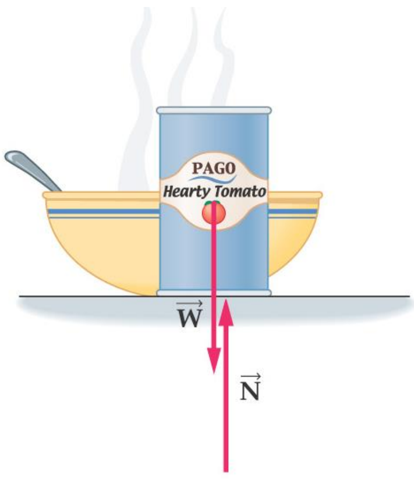
- What is the apparent weight of the salmon $\mathbf{W}_a$, if the elevator moves with downward acceleration of 3.2 m/s^2 ?

Answer: (33 N)y



5-7- Normal Forces

- ✓ The normal force is the force exerted by a surface on an object.
- ✓ The normal force may be equal to, greater than, or less than the weight.
- ✓ The normal force is always perpendicular to the surface
- ✓ Normal Force = Weight

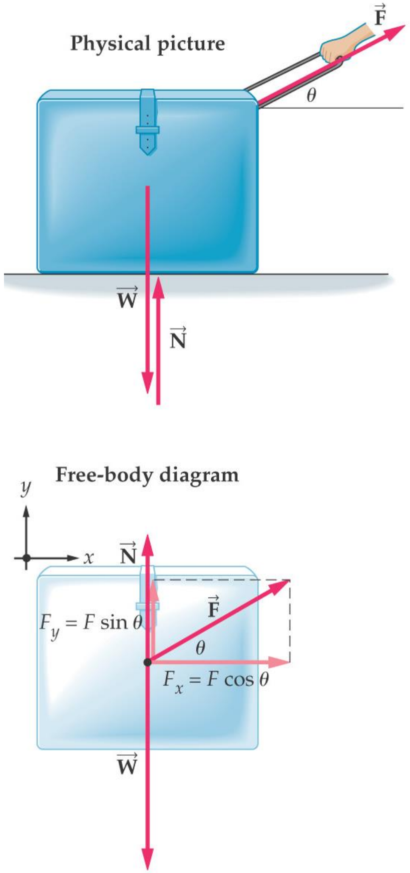


Physical picture

Free-body diagram

Normal force < Weight

Calculate the normal force?
If the mass of the suitcase =12.0 kg,
F=45.0 N, Angle = 20.0^{o}



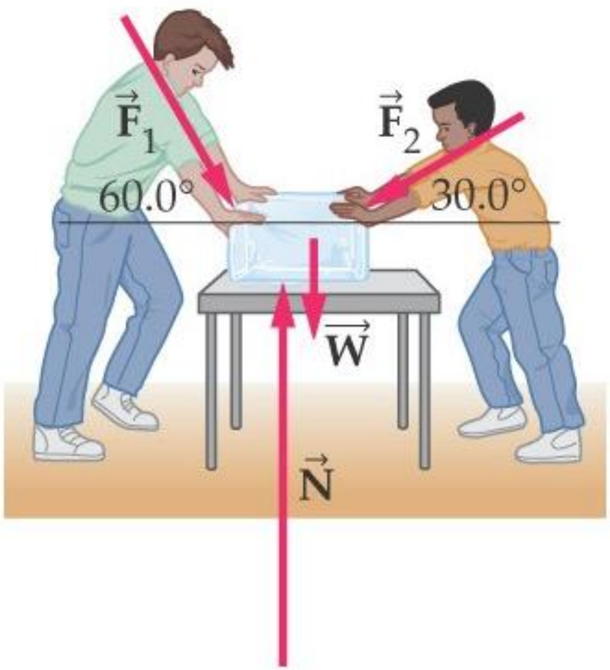
Answer

N = (103 N)y

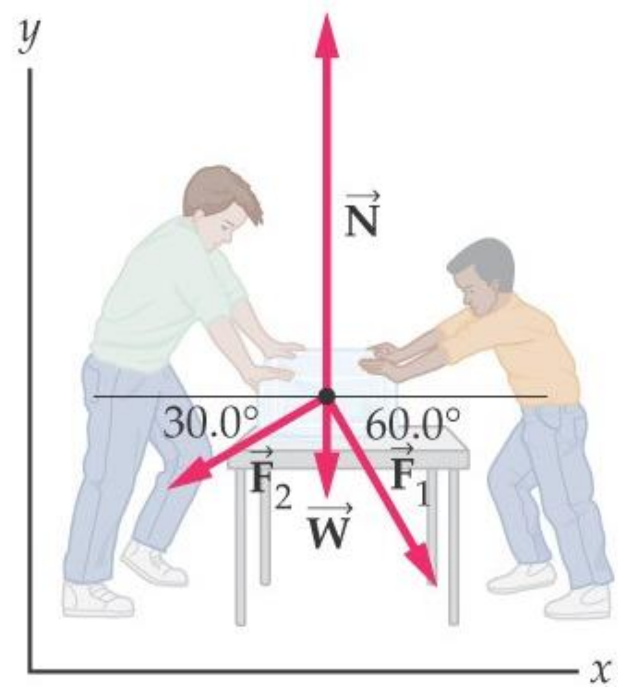
Normal force > Weight

Calculate the acceleration of the ice and the normal force exerted on it by the table? m=6.0kg , F1=13N , F2=11N

Answers: **a**= (-0.50m/s^2)x , **N**= (75N)y



Physical picture



Free-body diagram

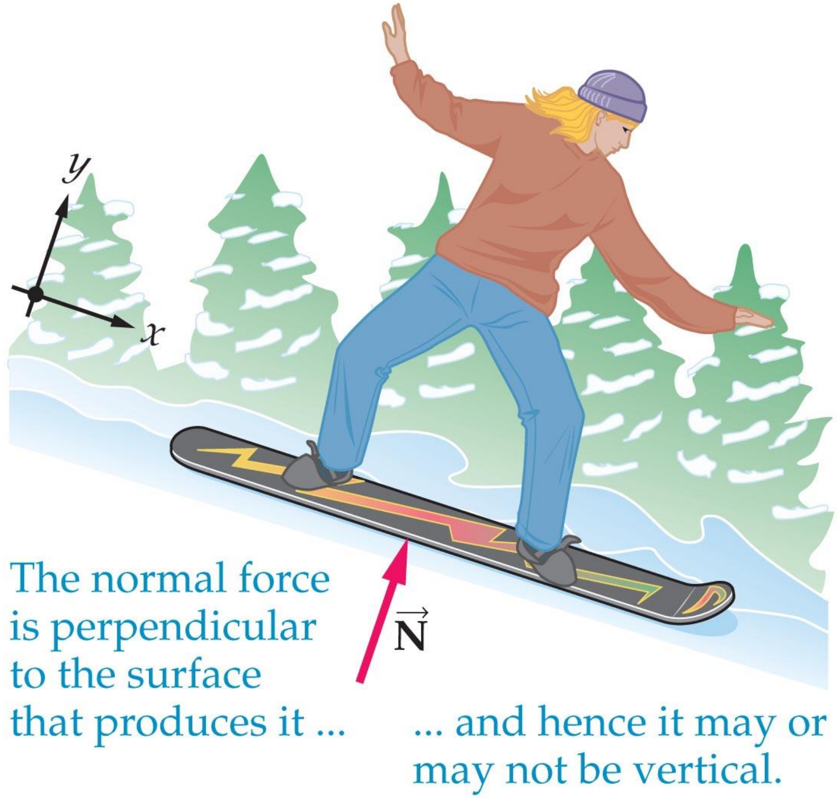
The normal Force N is always at right angles to the surface
It is not always in the vertical direction.

What is the acceleration and normal force exerted on the person by toboggan?

Answers

a= g sinϴ

N=mg cosϴ



Summary of Chapter 5

- Force: a push or pull
- Mass: measures the difficulty in accelerating an object
- Newton’s first law: if the net force on an object is zero, its velocity is constant
- Inertial frame of reference: one in which the first law holds
- Newton’s second law: $\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$
- Free-body diagram: a sketch showing all the forces on an object

- Newton’s third law: If object 1 exerts a force $\vec{\mathbf{F}}$ on object 2, then object 2 exerts a force $-\vec{\mathbf{F}}$ on object 1.

- Contact forces: an action-reaction pair of forces produced by two objects in physical contact

- Forces are vectors

- Newton’s laws can be applied to each component of the forces independently

- Weight: gravitational force exerted by the Earth on an object

- On the surface of the Earth, $W = mg$
- Apparent weight: force felt from contact with a floor or scale
- Normal force: force exerted perpendicular to a surface by that surface
- Normal force may be equal to, lesser than, or greater than the object's weight

Exercises

(1) On a planet far, far away, an astronaut picks up a rock that has a mass of 5.00kg, and on this particular planet its weight is 40.0N.If the astronaut exerts an upward force of 46.2N on the rock, what is its acceleration.

Answers: F = (6.2N) i , a = 1.2 m/s^2 j

(2) In a grocery store, you push a 12.3kg shopping cart with a force of 10.1N. If the cart starts at rest, how far does it move in 2.50s?

Answers: a= (0.821) i , Δx = 2.57 m

(3) You are pulling your little sister on her sled across an icy(frictionless) surface. When you exert a constant horizontal force of 120N,the sled has an acceleration of 2.5m/s^2. If the sled has a mass of 7.4kg,what is the mass of your little sister? Answer : 41 kg

(4) A 0.53 kg billiard ball initially at rest is given a speed of 12 m/s during a time interval of 4.0 ms. What average force acted on the ball during this time.

Answer: 1590 N

(5) A 92 kg water skier floating in a lake is pulled from rest to a speed of 12 m/s in a distance of 25 m. What is the net force exerted on the skier, assuming his acceleration is constant. Answer: 265 N

Exercises

Problem 38

Suppose a rocket Launches with an acceleration of 30.5 m/s^2. What is the apparent weight of a 92 kg astronaut abroad this rocket?

Answer: 3700 N