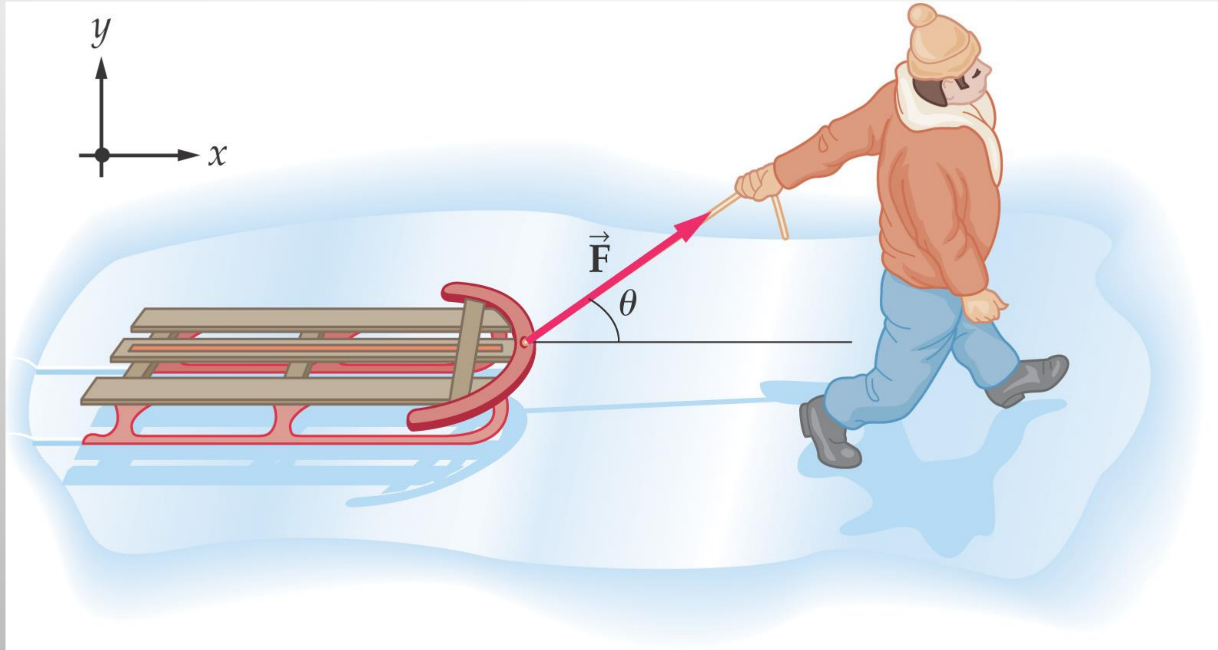
# NEWTON'S LAWS OF MOTION

# Force

- Force: push or pull
- Force is a vector – it has magnitude and direction
  - The SI unit of *force* is the **newton.** The SI symbol for the newton is N.



CONCEPT CHECK

What is Newton’s first law of motion?

# NEWTON'S 1ST LAW - LAW OF INERTIA

**NEWTON'S FIRST LAW STATES THAT EVERY OBJECT CONTINUES IN A STATE OF REST, OR OF UNIFORM SPEED IN A STRAIGHT LINE, UNLESS ACTED ON BY A NONZERO NET FORCE OR UNBALANCED FORCE.**

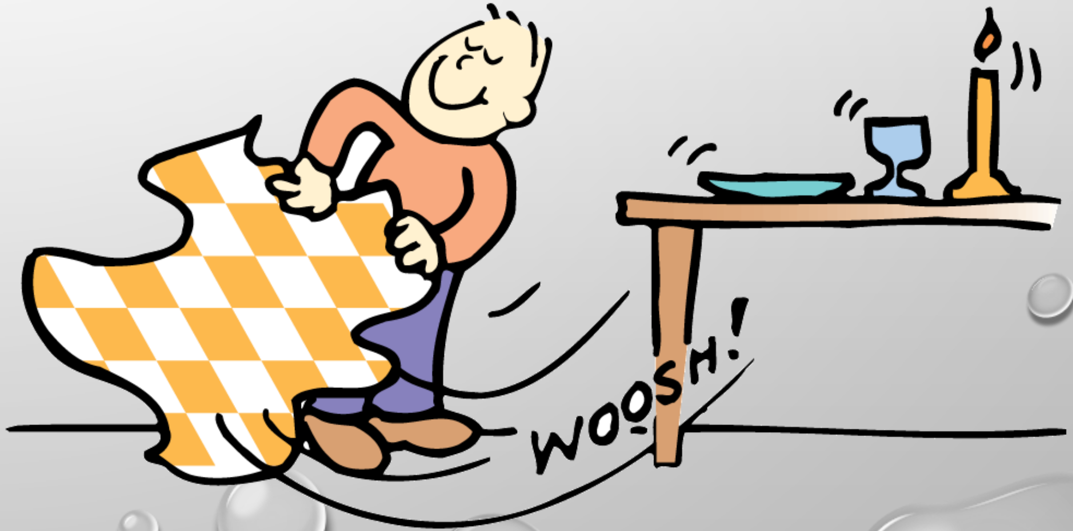
- COMBINATION OF FORCES ACTING ON AN OBJECT IS THE *NET FORCE*.
- IF NET FORCE IS EQUAL TO ZERO, ITS VELOCITY IS CONSTANT.

THE PROPERTY OF A BODY TO RESIST CHANGES TO ITS STATE OF MOTION IS CALLED **INERTIA**.

# NEWTON'S LAW OF INERTIA: OBJECTS AT REST

**SIMPLY PUT, THINGS TEND TO KEEP ON DOING WHAT THEY'RE ALREADY DOING.**

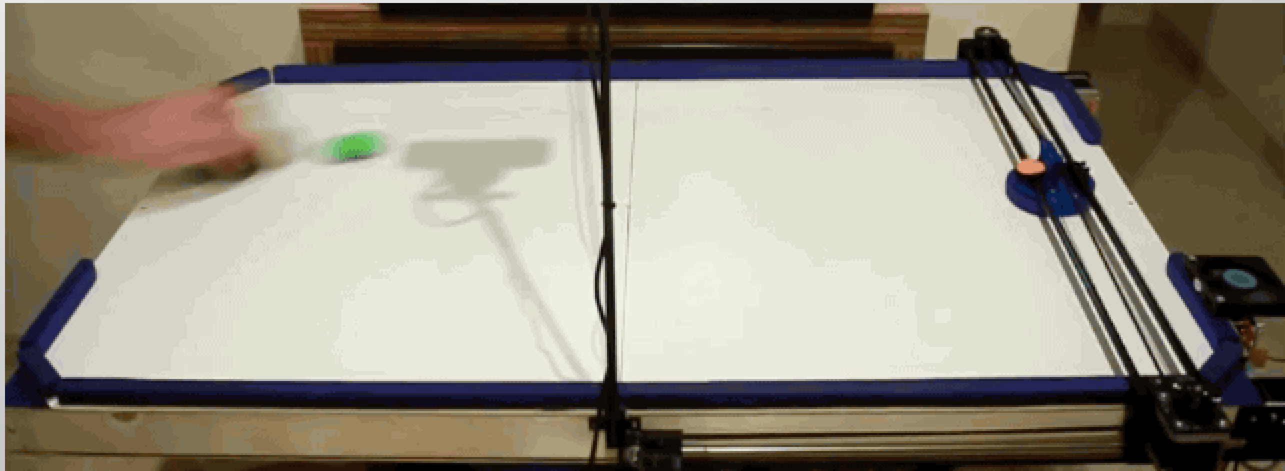
- OBJECTS IN A STATE OF REST TEND TO REMAIN AT REST. (NET FORCE = 0)
- ONLY AN UNBALANCED FORCE WILL CHANGE THAT STATE.



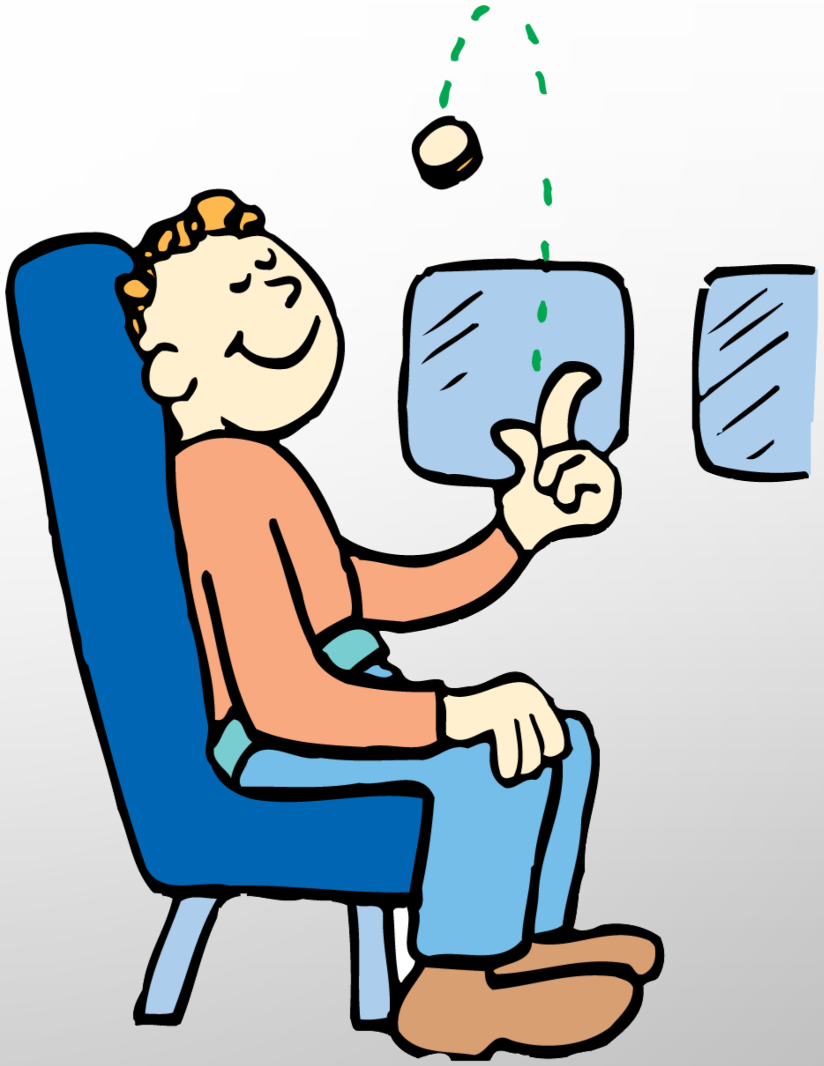
# NEWTON'S LAW OF INERTIA: OBJECTS IN MOTION

**NOW CONSIDER AN OBJECT IN MOTION.**

- IN THE ABSENCE OF FORCES, A MOVING OBJECT TENDS TO MOVE IN A STRAIGHT LINE INDEFINITELY.
- TOSS AN OBJECT FROM A SPACE STATION LOCATED IN THE VACUUM OF OUTER SPACE, AND THE OBJECT WILL MOVE FOREVER DUE TO INERTIA.



Flip a coin in an airplane, and it behaves as if the plane were at rest. The coin keeps up with you—inertia in action!



## THINK!

- A FORCE OF GRAVITY BETWEEN THE SUN AND ITS PLANETS HOLDS THE PLANETS IN ORBIT AROUND THE SUN. IF THAT FORCE OF GRAVITY SUDDENLY DISAPPEARED, IN WHAT KIND OF PATH WOULD THE PLANETS MOVE?

- *ANSWER:* EACH PLANET WOULD MOVE IN A STRAIGHT LINE AT CONSTANT SPEED.

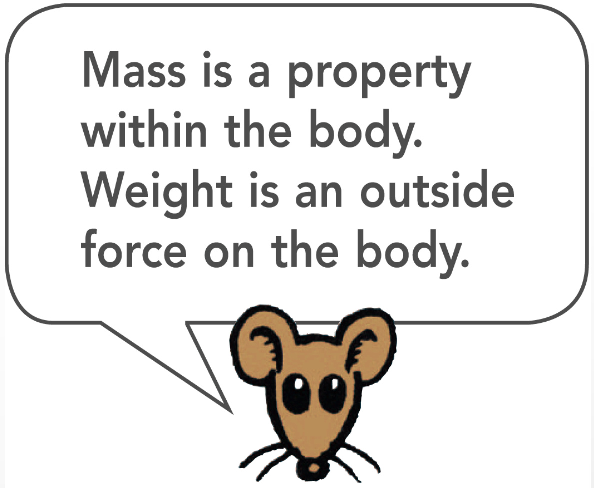
CONCEPT CHECK

**What is the relationship between mass and inertia?**

# MASS—A MEASURE OF INERTIA

- **THE MORE MASS AN OBJECT HAS, THE GREATER ITS INERTIA AND THE MORE FORCE IT TAKES TO CHANGE ITS STATE OF MOTION.**
  - MASS IS MEASURED IN THE FUNDAMENTAL UNIT OF **KILOGRAMS.**

# Mass—A Measure of Inertia




Mass is often confused with *weight*.

- Mass is a measure of the amount of material in an object.
- Mass is a measure of the inertia, or “laziness,” that an object exhibits in response to any effort made to start it, stop it, or otherwise change its state of motion.

- Weight ($F_g$) is measure of the gravitational force acting on the object.

**Definition: Weight, *W***

$$W = mg$$

SI unit: newton, N

**THINK!**

DOES A 2-KILOGRAM BUNCH OF BANANAS HAVE TWICE AS MUCH *INERTIA* AS A 1-KILOGRAM LOAF OF BREAD?

*ANSWER:* TWO KILOGRAMS OF *ANYTHING* HAS TWICE THE INERTIA AND TWICE THE MASS OF ONE KILOGRAM OF ANYTHING ELSE.

# NEWTON'S 2ND LAW

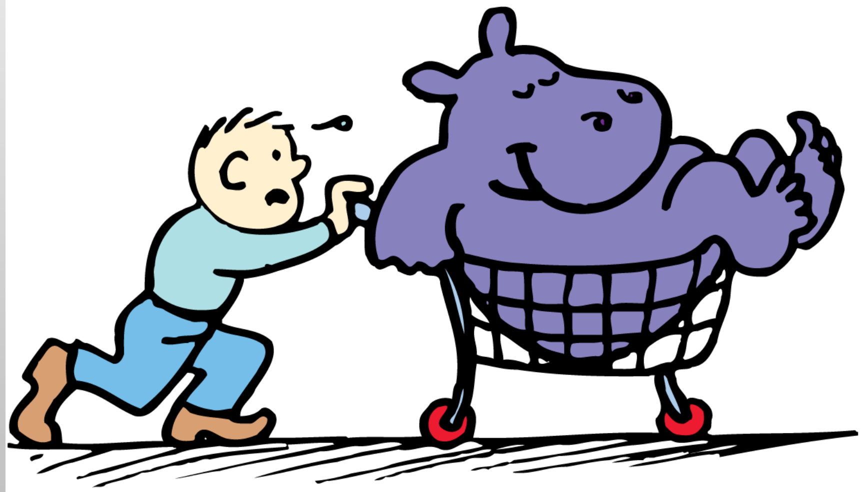
- **NEWTON'S SECOND LAW STATES THAT THE ACCELERATION PRODUCED BY A NET FORCE ON AN OBJECT IS DIRECTLY PROPORTIONAL TO THE MAGNITUDE OF THE NET FORCE, IS IN THE SAME DIRECTION AS THE NET FORCE, AND IS INVERSELY PROPORTIONAL TO THE MASS OF THE OBJECT.**

- **UNBALANCED FORCES (NET FORCE) ACTING ON AN OBJECT CAUSE THE OBJECT TO ACCELERATE.**
  - TO INCREASE THE ACCELERATION OF AN OBJECT, YOU MUST INCREASE THE NET FORCE ACTING ON IT.

$$\text{acceleration} = \frac{\text{net force}}{\text{mass}} \qquad a = \frac{F}{m}$$

# NEWTON'S 2ND LAW

- HOW DOES AN INCREASE IN MASS AFFECT ACCELERATION?
- FOR A CONSTANT FORCE, AN INCREASE IN THE MASS WILL RESULT IN A DECREASE IN THE ACCELERATION.



## THINK!

- IF A CAR CAN ACCELERATE AT 2 $M/S^2$, WHAT ACCELERATION CAN IT ATTAIN IF IT IS TOWING ANOTHER CAR OF EQUAL MASS?

- *ANSWER:* THE SAME FORCE ON TWICE THE MASS PRODUCES HALF THE ACCELERATION, OR 1 $M/S^2$.

**HOW MUCH FORCE, OR THRUST, MUST A 30,000-KG JET PLANE DEVELOP TO ACHIEVE AN ACCELERATION OF 1.5 M/S$^2$?**

ARRANGE NEWTON'S SECOND LAW TO READ:

FORCE = MASS × ACCELERATION

$F = MA$

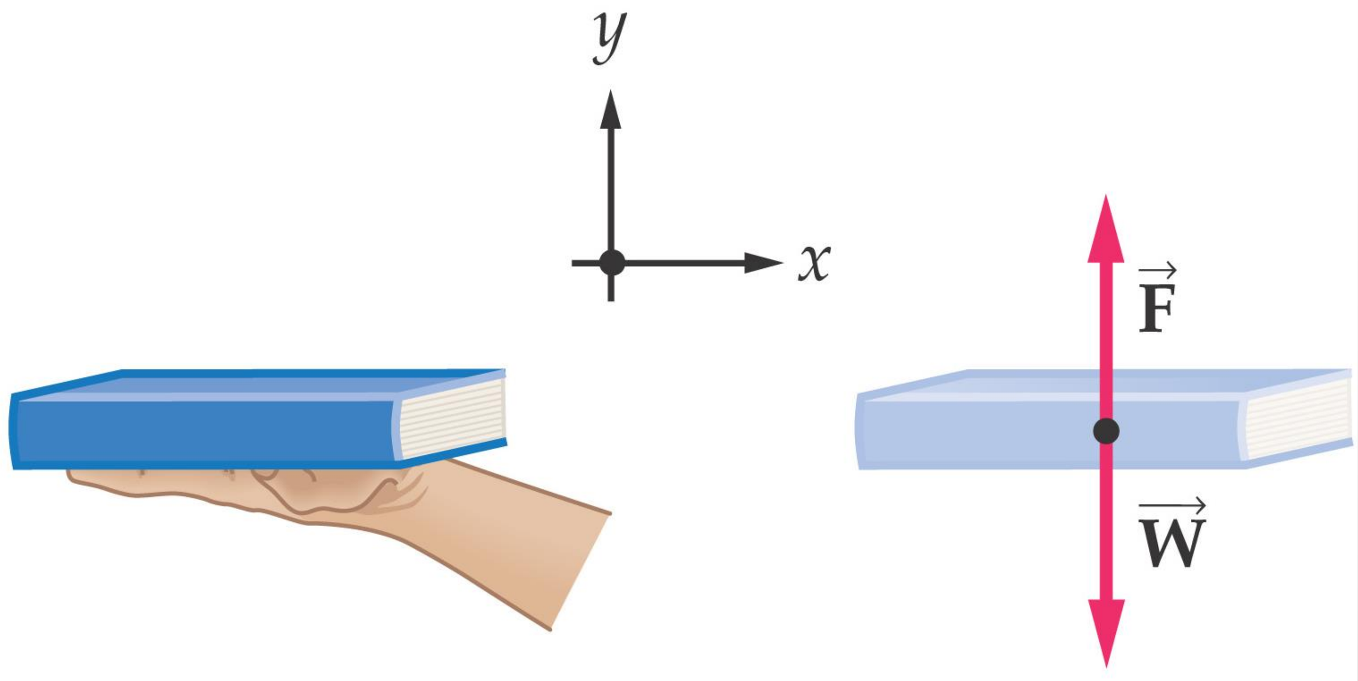
$= (30{,}000\ \text{KG})(1.5\ \text{M/S}^2)$

$= 45{,}000\ \text{KG}\bullet\text{M/S}^2$

$= 45{,}000\ \text{N}$

# Newton's Second Law of Motion

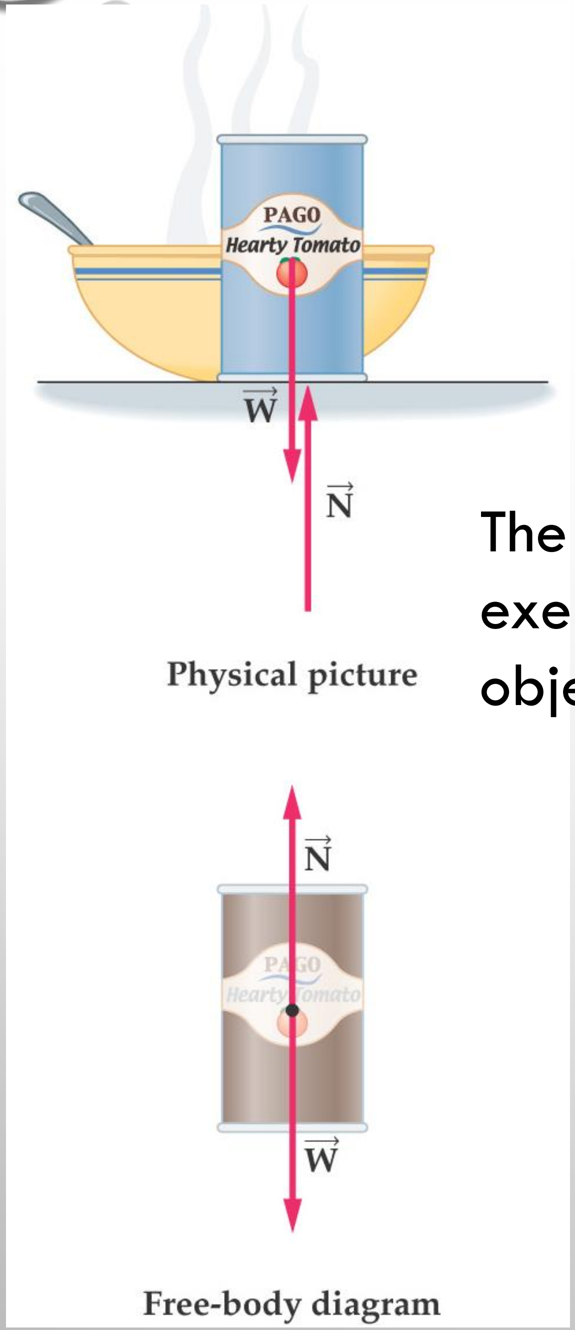
Example of a free-body diagram:



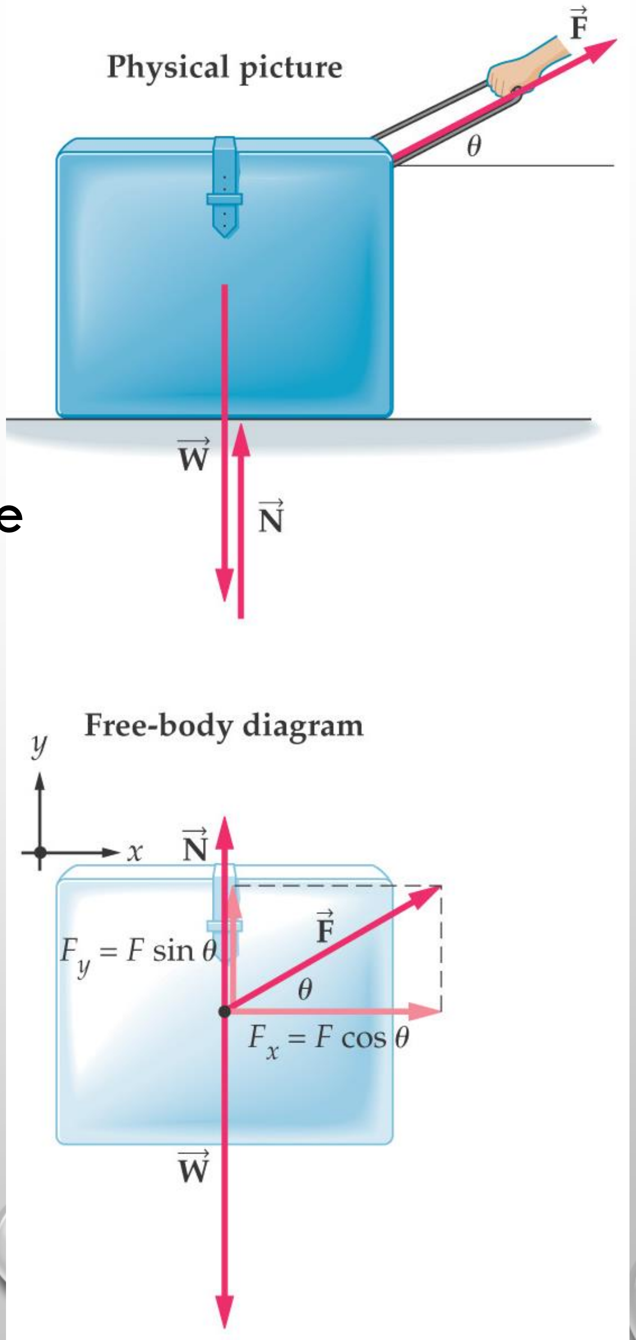

(a)
Physical picture

(b)
Free-body diagram

# Normal Forces

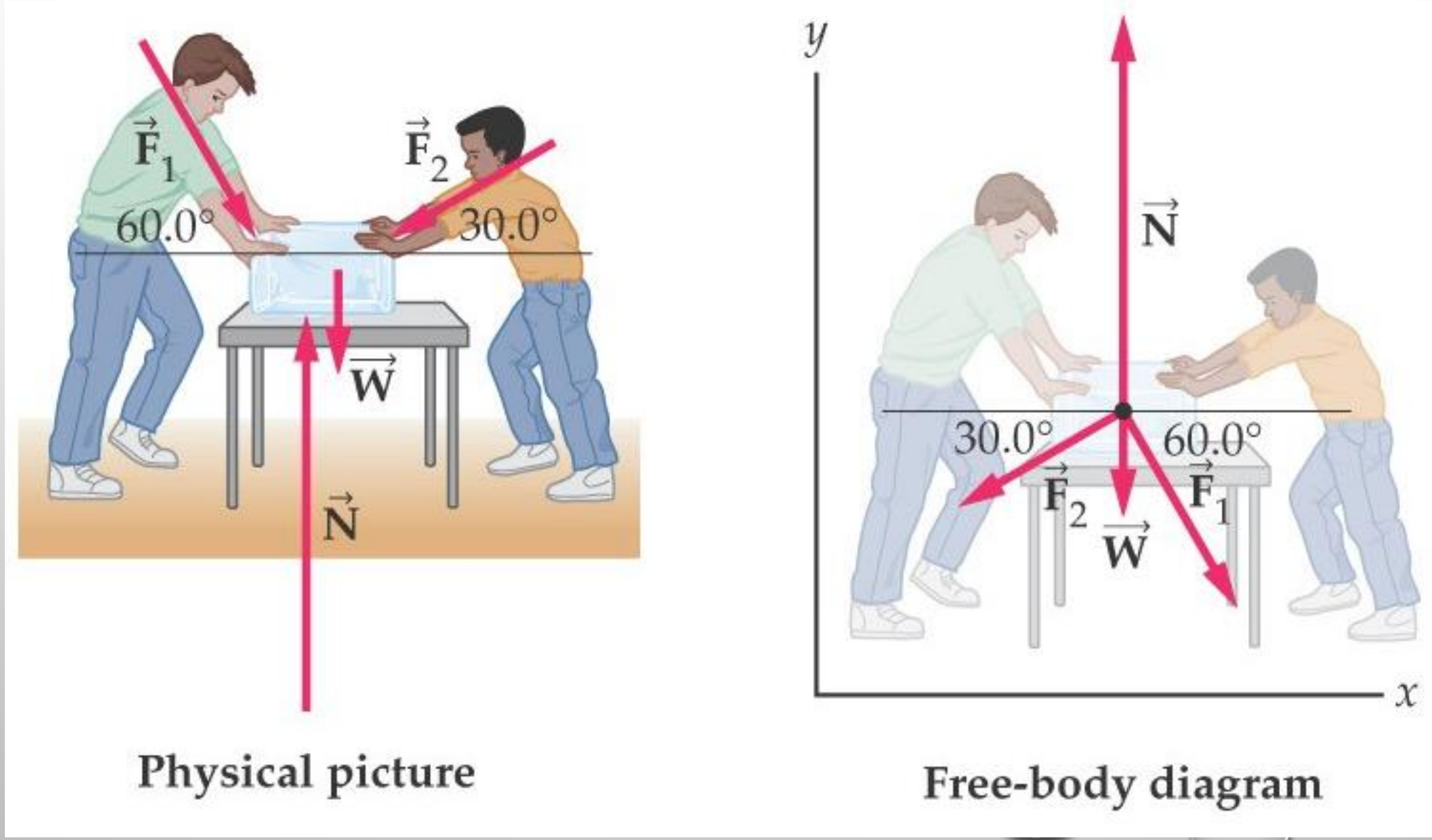



The normal force is the force exerted by a surface on an object.



# Normal Forces

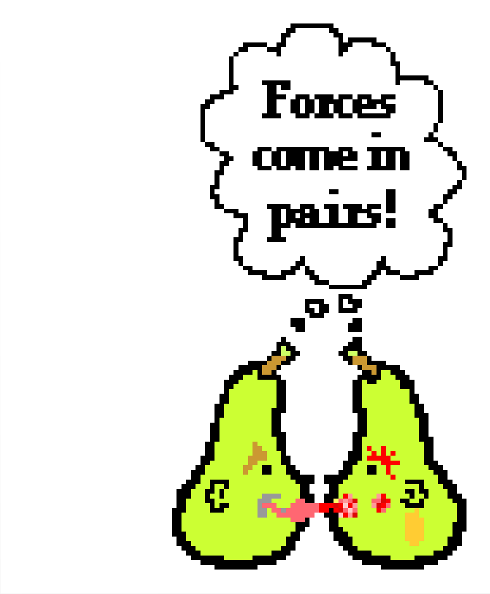
The normal force may be equal to, greater than, or less than the weight.

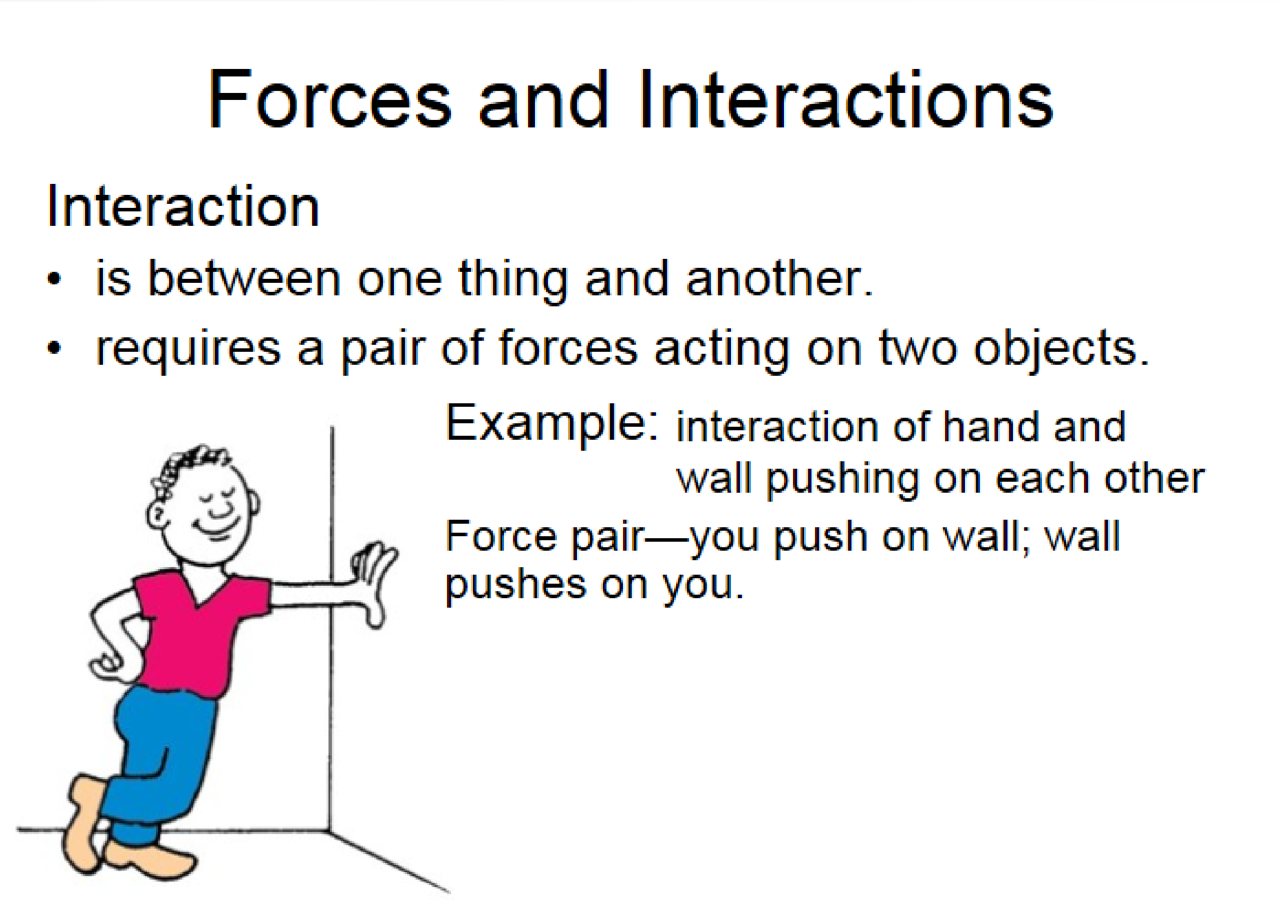


# Normal Forces

The normal force is always perpendicular to the surface.

# NEWTON'S $3^{RD}$ LAW




- WHENEVER ONE OBJECT EXERTS A FORCE ON A SECOND OBJECT, THE SECOND OBJECT EXERTS AN EQUAL AND OPPOSITE FORCE ON THE FIRST.

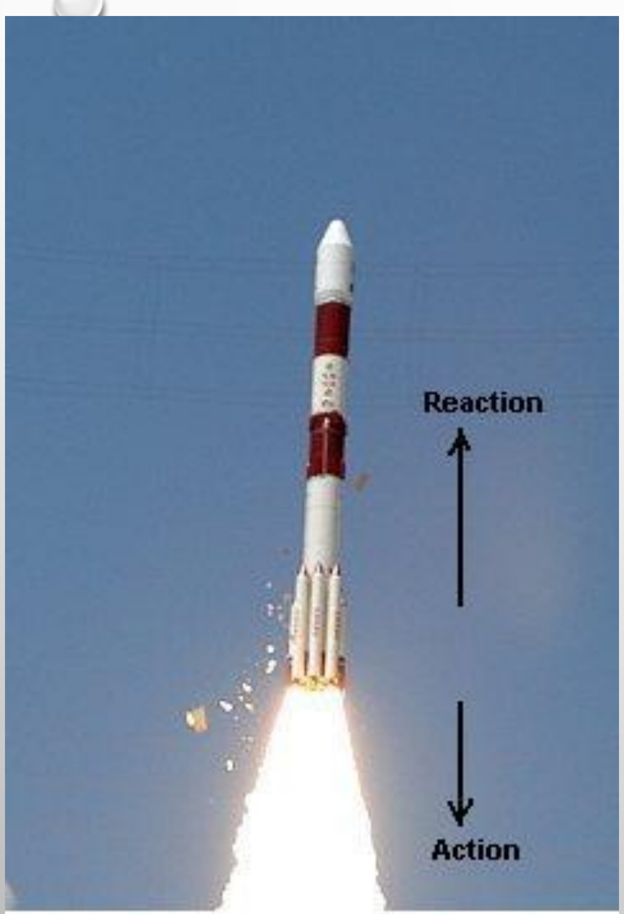
- A SOCCER PLAYER KICKS A BALL WITH 1500N OF FORCE. THE BALL EXERTS A REACTION FORCE AGAINST THE PLAYER'S FOOT OF
  a) SOMEWHAT LESS THAN 1500 N
  b) 1500 N
  c) SOMEWHAT MORE THAN 1500 N

# NEWTON'S 3RD LAW

## Action and reaction forces

- one force is called the action force; the other force is called the reaction force.
- are co-pairs of a single interaction.
- neither force exists without the other.
- are equal in strength and opposite in direction.
- always act on *different* objects.

# NEWTON'S 3$^{RD}$ LAW

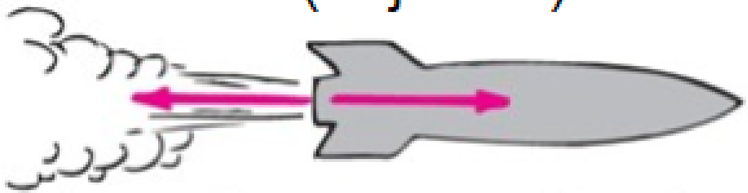


A rocket is driven by Newton's Third Law of Motion (Action Triggers Reaction)

## Simple rule to identify action and reaction

- Identify the interaction—one thing interacts with another
  - Action: Object A exerts a force on object B.
  - Reaction: Object B exerts a force on object A.

  Example: Action—rocket (object A) exerts force on gas (object B).
  Reaction—gas (object B) exerts force on rocket (object A).



- WHEN YOU STEP OFF A CURB, EARTH PULLS YOU DOWNWARD.  THE REACTION TO THIS FORCE IS
  a) A SLIGHT AIR RESISTANCE
  b) NONEXISTENT IN THIS CASE
  c) YOU PULLING EARTH UPWARD.

- WHY DO YOU NOT SENSE EARTH MOVING UPWARD TOWARD YOU?
  a) IT MOVES, BUT A VERY SMALL AMOUNT
  b) EARTH CAN MOVE, BUT OTHER OBJECTS ON IT PREVENT IT FROM MOVING.
  c) EARTH IS FIXED, SO IT CANNOT MOVE

- **Avg. Mass of 1 human = 70 kg** or **154 lbs**
- **Acceleration = -10 m/s2**
- **Force = -700N**

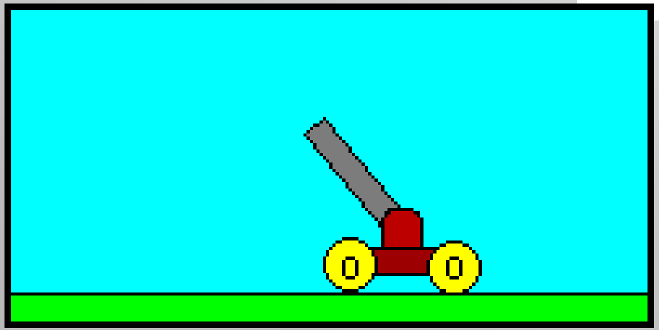
- Mass of Earth = 5.972 × 10^24 kg
- Acceleration = Force / mass

# Action and Reaction on Different Masses

Cannonball: $\frac{F}{m} = \mathbf{a}$

Cannon: $\frac{F}{\mathbf{m}} = a$

- The same force exerted on a small mass produces a large acceleration.
- The same force exerted on a large mass produces a small acceleration.



# Summary of Newton's Three Laws of Motion

- Newton's first law of motion (the law of inertia)
  - An object at rest tends to remain at rest; an object in motion tends to remain in motion at constant speed along a straight-line path.
- Newton's second law of motion (the law of acceleration)
  - When a net force acts on an object, the object will accelerate. The acceleration is directly proportional to the net force and inversely proportional to the mass.
- Newton's third law of motion (the 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.