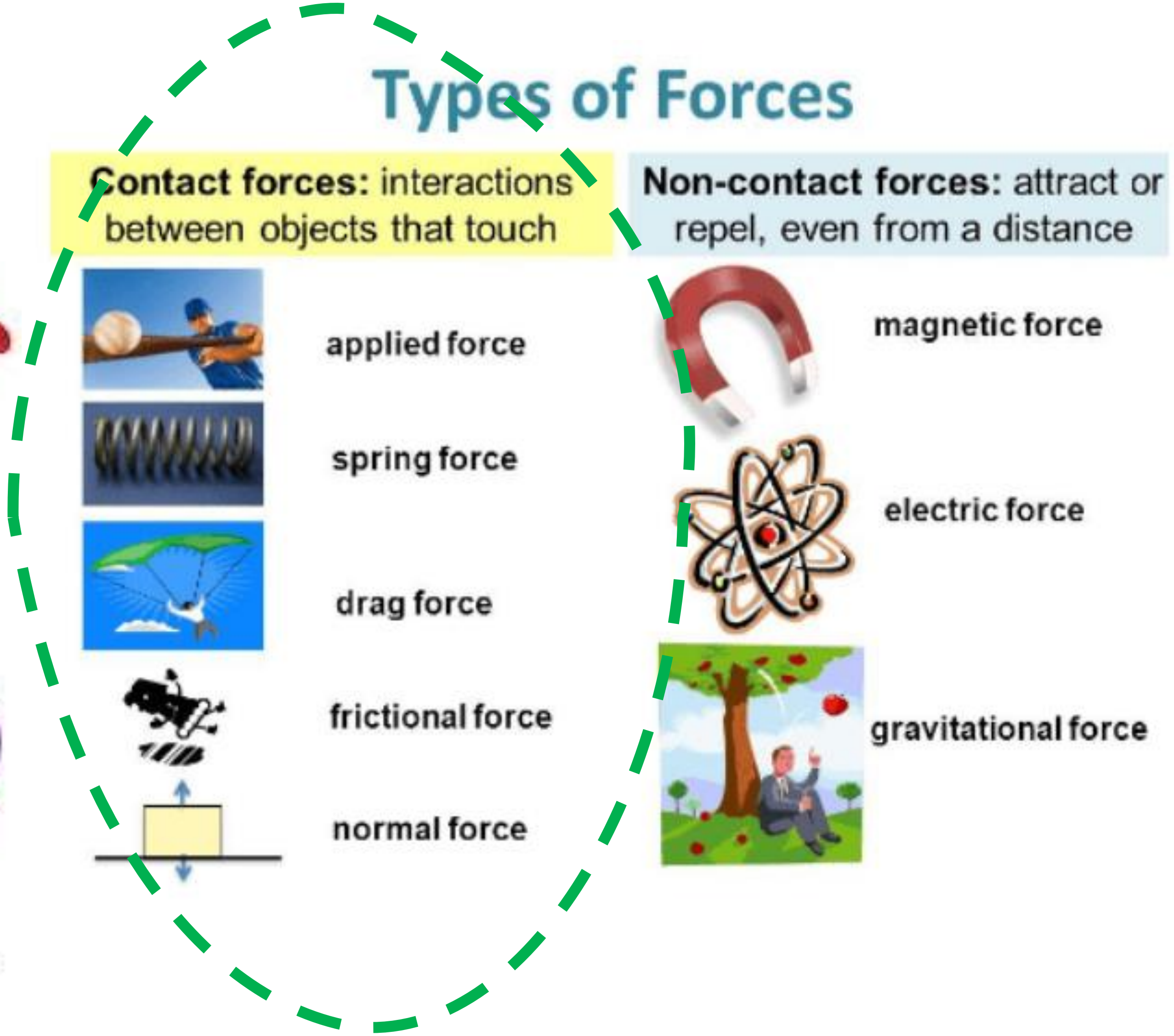
Units of Chapter 4

- Force
- Newton's First Law of Motion
- Mass
- Newton's Second Law of Motion
- Newton's Third Law of Motion
- Weight—the Force of Gravity; and the Normal Force
- Solving Problems with Newton's Laws: Free-Body Diagrams
- Problem Solving—A General Approach

What is force?

Answer: a push or a pull.

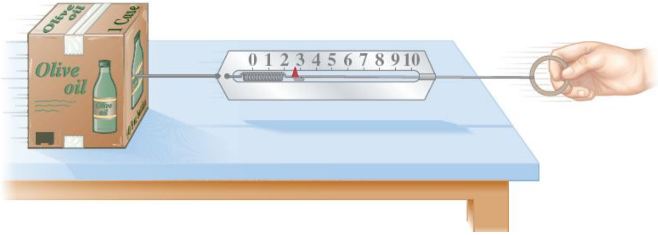


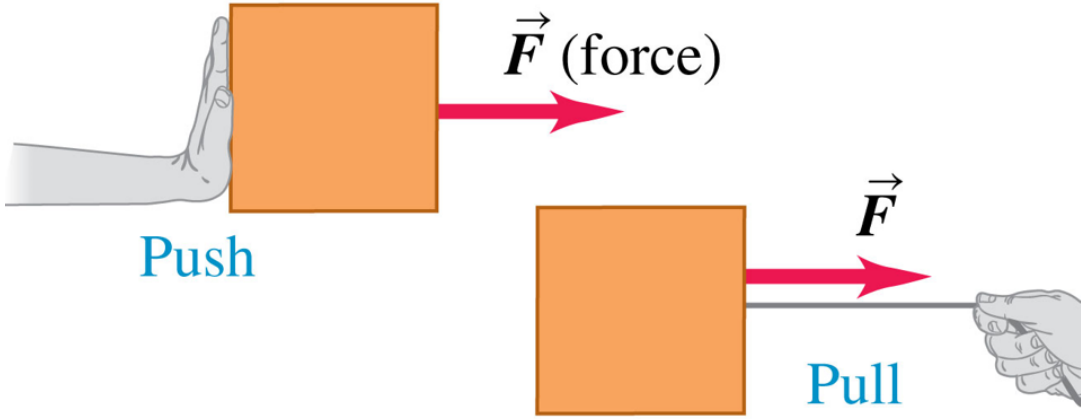
4-1 Force

A force is a push or pull. An object at rest needs a force to get it moving; a moving object needs a force to change its velocity.

A force is an interaction between two objects or between an object and its environment

Force is a vector, having both magnitude and direction. The magnitude of a force can be measured using a spring scale





In general we can state that if a system of two or more forces are applied on a object, the net force on this object will be given by:

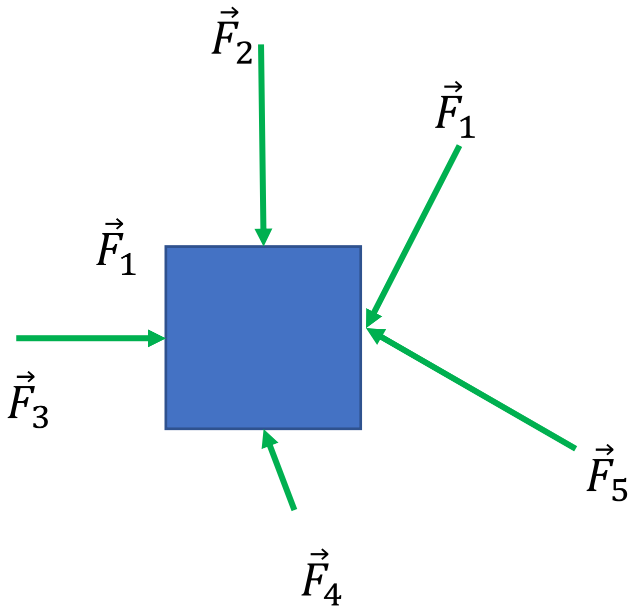
$$\vec{\boldsymbol{F}} = \sum_{i=1}^{N} \vec{F}_i$$

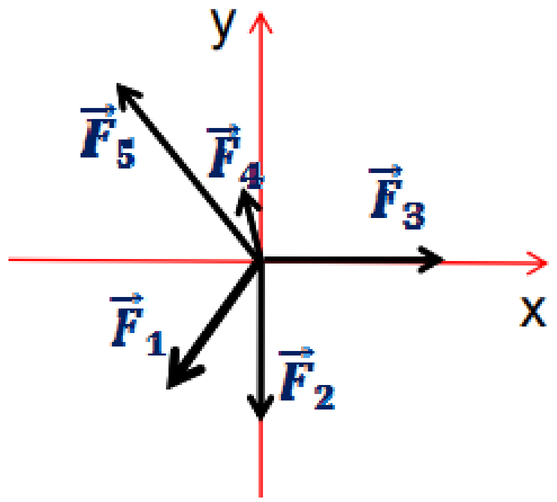
Where the subscript " i " in $\vec{F}_i$ denotes a particular force acting on the object; "i " can be any number between 1 and N; N is the total number of forces applied on the object. The Greek symbol Σ denotes a summation over all possible forces from 1 to N

Determine the net force $\vec{\boldsymbol{F}}$ acting on an object subject to five different forces

$\vec{F}_1$; $\vec{F}_2$; $\vec{F}_3$; $\vec{F}_4$ and $\vec{F}_5$

$$\vec{\boldsymbol{F}} = \sum_{i=1}^{5} \vec{F}_i = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \vec{F}_4 + \vec{F}_5$$

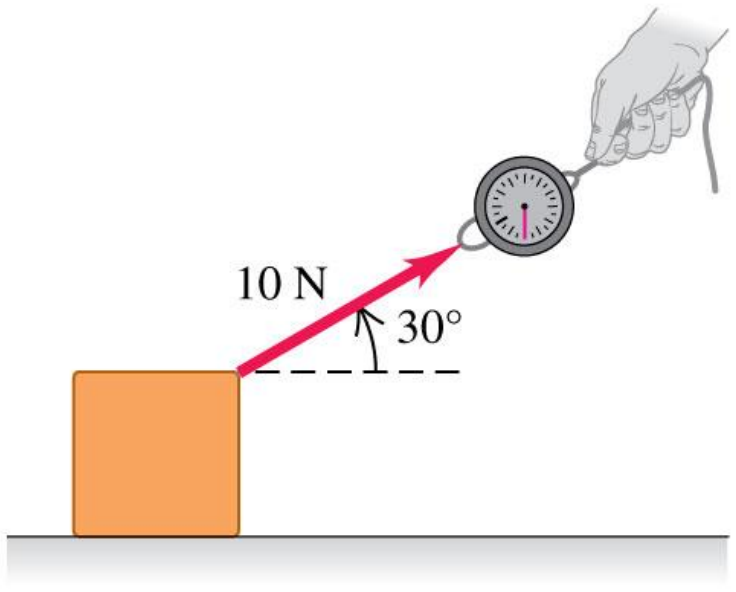




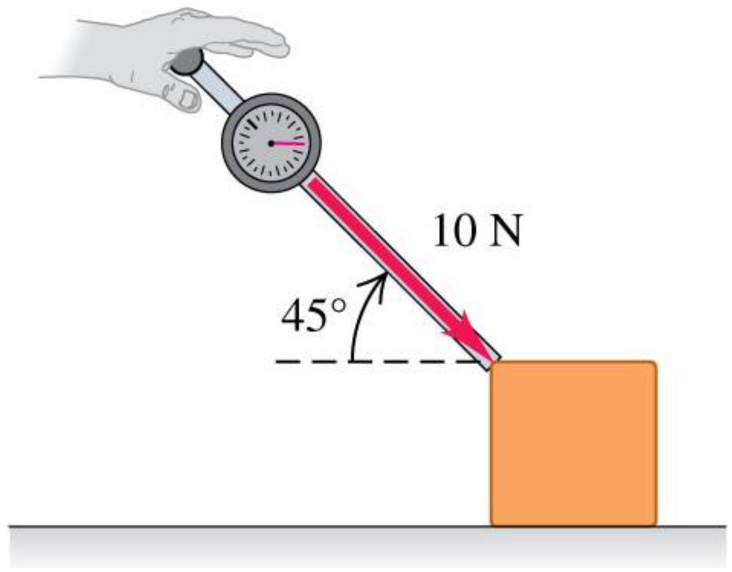
Drawing force vectors—

- Use a vector arrow to indicate the magnitude and direction of the force.

(a) A 10-N pull directed 30° above the horizontal



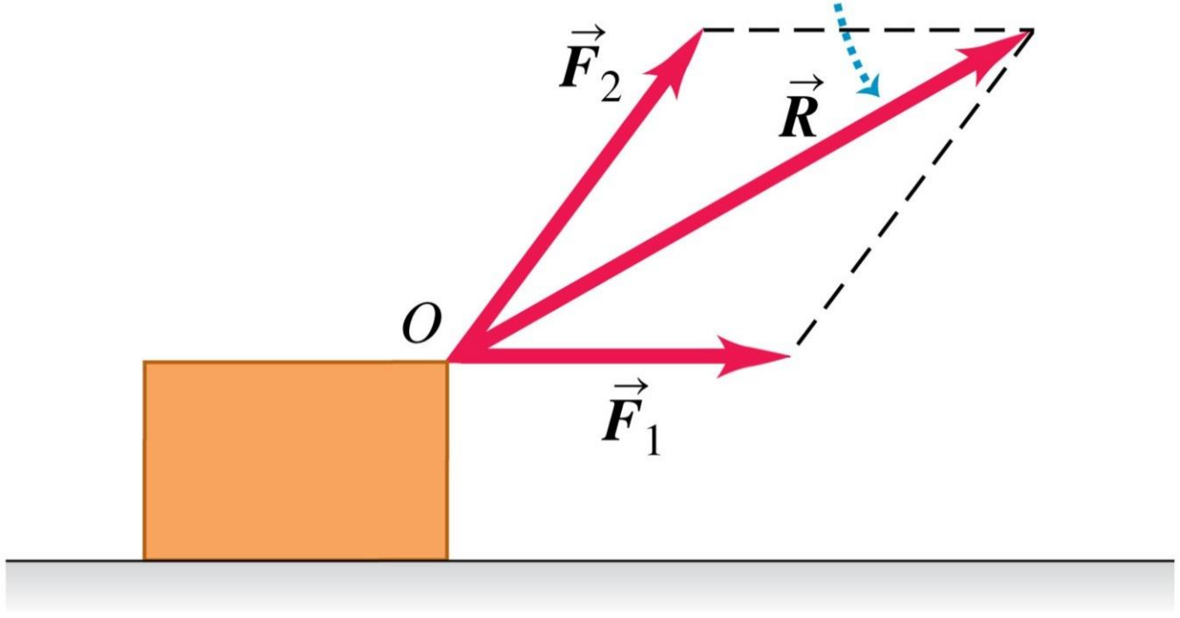
(b) A 10-N push directed 45° below the horizontal



Superposition of force

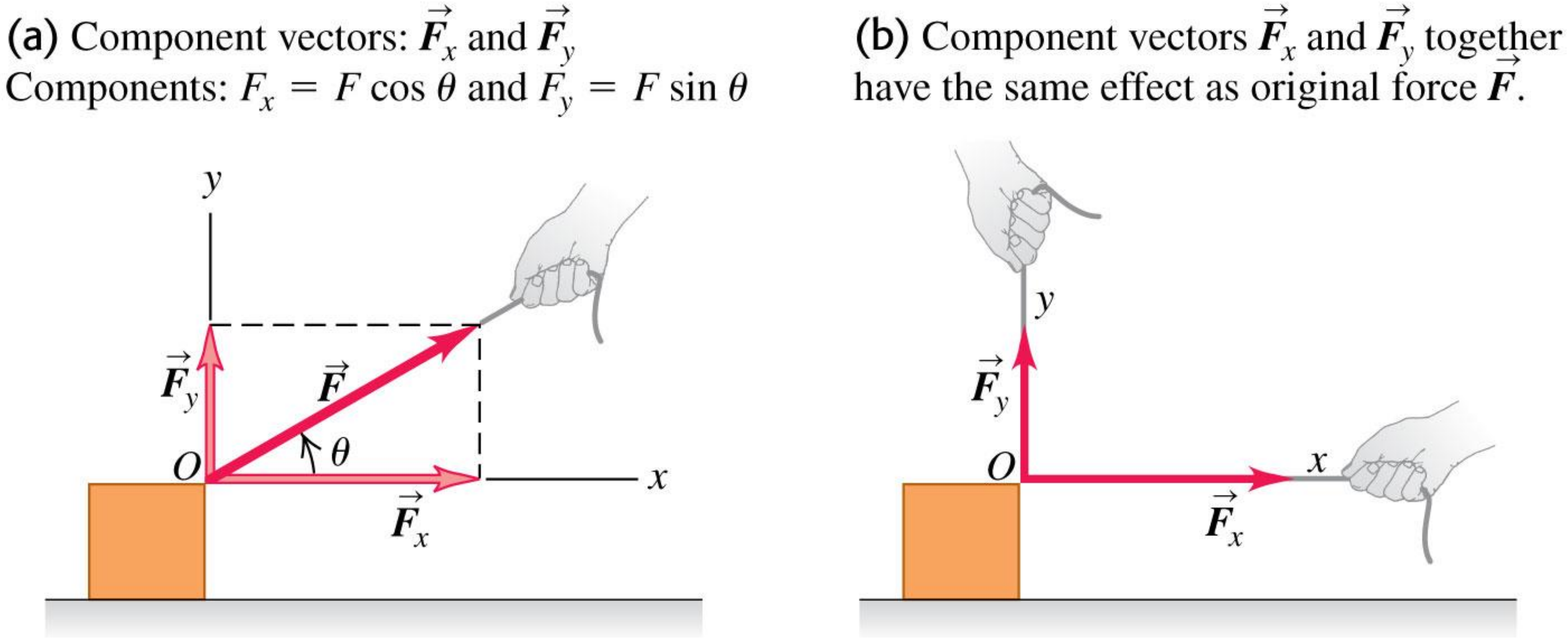
- Several forces acting at a point on an object have the same effect as their vector sum acting at the same point.

Two forces $\vec{F}_1$ and $\vec{F}_2$ acting on a body at point O have the same effect as a single force $\vec{R}$ equal to their vector sum.



Decomposing a force into its component vectors

- Choose perpendicular x and y axes.
- F_x and F_y are the components of a force along these axes.
- Use trigonometry to find these force components.



Newton's Laws of Motion Relationship between force and motion

We have seen that given a reference frame, an object can be found in any of the following states of motion:

- at rest
- moving with constant velocity
- accelerated

But an applied force on an object can change its state of motion:

- The object can starting moving from rest
- Can change velocity from a state of constant velocity
- Can change direction (and therefore the vector velocity), and may be the magnitude of its velocity.

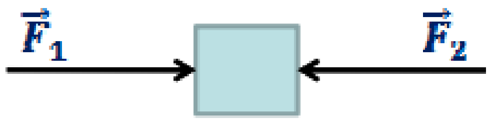
It is clear that if NO forces are applied on an object, it will tend to remain on its original state of motion.

Example: An object initially at rest is suddenly subjected to two forces, $\vec{F}_1 and\ \vec{F}_2$ and , of same magnitude and opposite direction. What is the net force acting on this object? Will it move? Answer: Let be the net force, then:

Answer:

Let $\vec{F}$ be the net force, then:

$$\vec{F} = \sum_{i=1}^{2} \vec{F}_i = \vec{F}_1 + \vec{F}_2$$



But $\vec{F}_2 = -\vec{F}_1$, then

$$\vec{F} = \vec{F}_1 + \vec{F}_2 = \vec{F}_1 + (-\vec{F}_1)$$

$$\boxed{\vec{F} = 0}$$

Newton's Laws of Motion

Newton's First Law of Motion

We can generalize the previous statement to say that:

If the NET FORCE of all forces applied on a object is ZERO, then the object will tend to remain in its state of rest, or constant velocity.

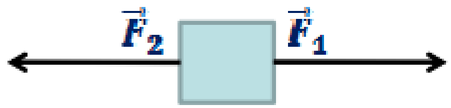
This follows from the fact that a **non-zero net force** will change the state of motion of any object, which implies **in changing its velocity** either in direction or magnitude or both. But, by definition, change in **velocity implies acceleration**. So, if **no acceleration** is present, the object will remain in its original state of motion.

We can then state the Newton's first law of motion as:

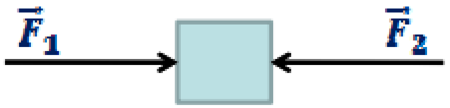
" Every Object continues in its state of rest, or uniform velocity in a straight line, as long as no net force acts on it

Newton’s Laws of Motion

Note 1: You can always represent the forces on the previous diagram



as instead of



This can be generalized to any system of forces

Note 2: Newton’s first law ONLY holds in inertial frames.

Inertial frames are frames FIXED on a system which is either at rest or moving with constant velocity (no changes in direction and magnitude). Or, in other words, **inertial frames are those where the Newton’s first law is valid.**

Frames other than the inertial frames are called non-inertial frames (for obvious reasons). An example of non-inertial frame is that of a frame fixed on an accelerated system (example: a car).

Assume you are in a truck and have fixed the reference frame on a system at rest relative to the truck while moving at constant speed.

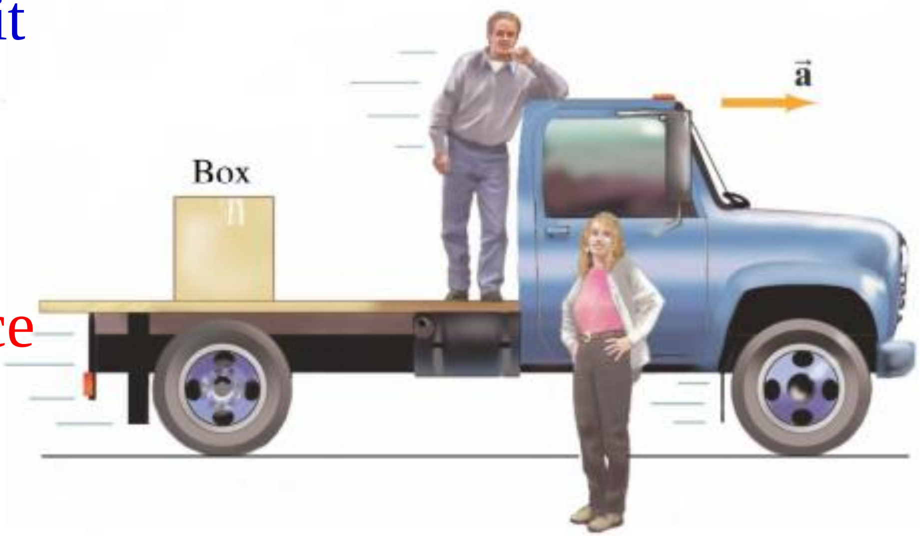
You then decide to accelerate the truck to increase its speed from a state of constant velocity

You will then notice that anything free on the passenger sit or anywhere on the truck will tend to move.

If you crash your truck on a wall, will also tend to tend to keep moving keep moving at the same velocity as before.

The reason is that the car is being accelerated due to a force applied to it (but not to you.)

For a person at rest relative to the ground, the box will seem to continue moving with constant velocity while the car is being accelerated (ignore effects due to



The Concept of Mass

Mass measures that quantity of matter in a body (or object).
It is given in units of Kg.

But then, you may ask me: What is matter????

The answer is even more complicate than that to understand how objects interact. We will not discuss about it here.

A alternative definition can be given as:

“Mass is a measure of the inertia of an object”

Inertia is the tendency an object has to continue in its state of motion.

You may have experienced the fact that it gets harder to move a box of some material as you add more of the same material to the box. So you are adding mass. This means that **adding mass in the box makes it more difficult to change its state of inertia**. So, mass is related to inertia: The **larger is the mass of an object, the larger is its inertia.**

Newton’s Second Law of Motion

$$v = v_0 + at$$
$$x = x_0 + v_0 t + \frac{1}{2} a t^2$$
$$v^2 = {v_0}^2 + 2a(x - x_0)$$
$$\bar{v} = \frac{v + v_0}{2}$$

We have seen that force and acceleration are related

In fact, acceleration is the product of an applied force.

We have also noticed that force and mass are also related more mass implies that a stronger force is needed to change the state of motion of a body.

But how are these quantities related??? From the equation of motion we know that:

$$v = at + v_0$$

If you triple (or double, or etc) your acceleration a, you expect to triple the velocity added to your motion, $v - v_0$. It is also observed that if you triple the applied force on an object, its change in velocity will be triple. It is then clear that force and acceleration are directly proportional.

$$\vec{F} \propto \vec{a}$$

We say: The symbol means ∝ “proportional to”

Newton’s Second Law of Motion:

It also has been observed that for the same applied force, the change in velocity will depend on the mass of the object: the greater the mass, the smaller is the change in velocity, the smaller is the acceleration.

So, here we can state the mass and acceleration are inversely proportional. This, together with $\vec{F} \propto \vec{a}$ led Newton to state his second law of motion:

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

Newton’s second law can be summarized with the following equation:

$$\vec{a} = \frac{\sum \vec{F}_i}{m}$$

where I have omitted the subscript “ i ” and the limits of summation: i and N (they are implicitly assumed to be present). This equation can be re-written to yield the well known relationship between force, mass and acceleration:

$$\vec{F} = \sum_{i=1}^{N} \vec{F}_i = m\vec{a}$$

Note that you can also write: ,

$$\vec{F} = \sum_{i=1}^{N} \vec{F}_i = \left(\sum_{i=1}^{N} m\vec{a}_i \right)$$

Where $\vec{F}_i = m\vec{a}_i$

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.

Units:

FORCE: **newton (N)** $1\ \mathrm{N} = \mathrm{kg} \cdot \mathrm{m/s^2}$

MASS: **kilogram (kg)**

Since $\sum \vec{F} = m\mathbf{a}$ this is a vector equation, it can be written in the component form:

$$\sum F_x = ma_x$$

$$\sum F_y = ma_y$$

$$\sum F_z = ma_z$$

Think

A bicycle has a mass of 13.1 kg and its rider has a mass of 81.7 kg. The rider is pumping hard so that a horizontal net force of 9.78 N accelerates them in the westward direction. What is the acceleration?

a) 0.103 m/s² west
b) .103 m/s² east
c) 0.120 m/s² west
d) 0.120 m/s² east
e) don't know.

m_{bike}	13.1 kg
m_{rider}	81.7 kg
F	9.79 N

$$a = \frac{F}{m_{bike} + m_{rider}}$$

$$= \frac{9.78N}{13.1kg + 81.7kg} = 0.103m/s^2$$

A catapult on an aircraft is capable of accelerating a plane from 0 to 56m/s in a distance of 80 m. Find the magnitude of the average net force that the catapult exerts on a 13300 kg jet.

Finding target Variable/Physical Quantity

m_{plane}	13300 kg
v_0	0
v	56 m/s
Δx	80 m

$$\Delta x = x_f - x_i$$

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

$$v^2 - v_0^2 = 2a\Delta x$$

$$a = \frac{v^2 - v_0^2}{2\Delta x} = \frac{v^2}{2\Delta x}$$

$$F = m\frac{v^2 - v_0^2}{2\Delta x}$$

$$= 13{,}300\frac{(56m/s)^2}{2(80m)} = 2.6x10^5\,N$$

Example A 0.140-kg baseball traveling 35.0 m/s strikes the catchers mitt, which, in bringing the ball to rest recoils backward 11.0 cm. What was the average force applied by the glove on the ball?

$$\sum \vec{F} = m\vec{a}$$

First find *a*: $x = +0.110\,m \;\; (to\,the\,right\,)$

$$v_0 = +35.0 \,{}^{m}\!/\!_{s}$$

$$v = 0$$

m_{ball}	**o.14kg**
$V_{initial\text{-}ball}$	3.5m/s
$V_{final\text{-}ball}$	o
Δx	11.0cm=.11m
a	?

$$v^2 = v_0^2 + 2a(x - x_0)$$

$$a = \frac{v^2 - v_0^2}{2(x - x_0)} = \frac{0 - \left(35.0 \,{}^{m}\!/\!_{s}\right)^2}{2(0.110\,m)} = -5.57 \times 10^3 \,{}^{m}\!/\!_{s^2}$$

$$\sum \vec{F} = m\vec{a}$$

$$F = (0.140kg)(-5.57 \times 10^3 \,{}^{m}\!/\!_{s^2})$$

(to the left)

Force is in opposite direction to velocity

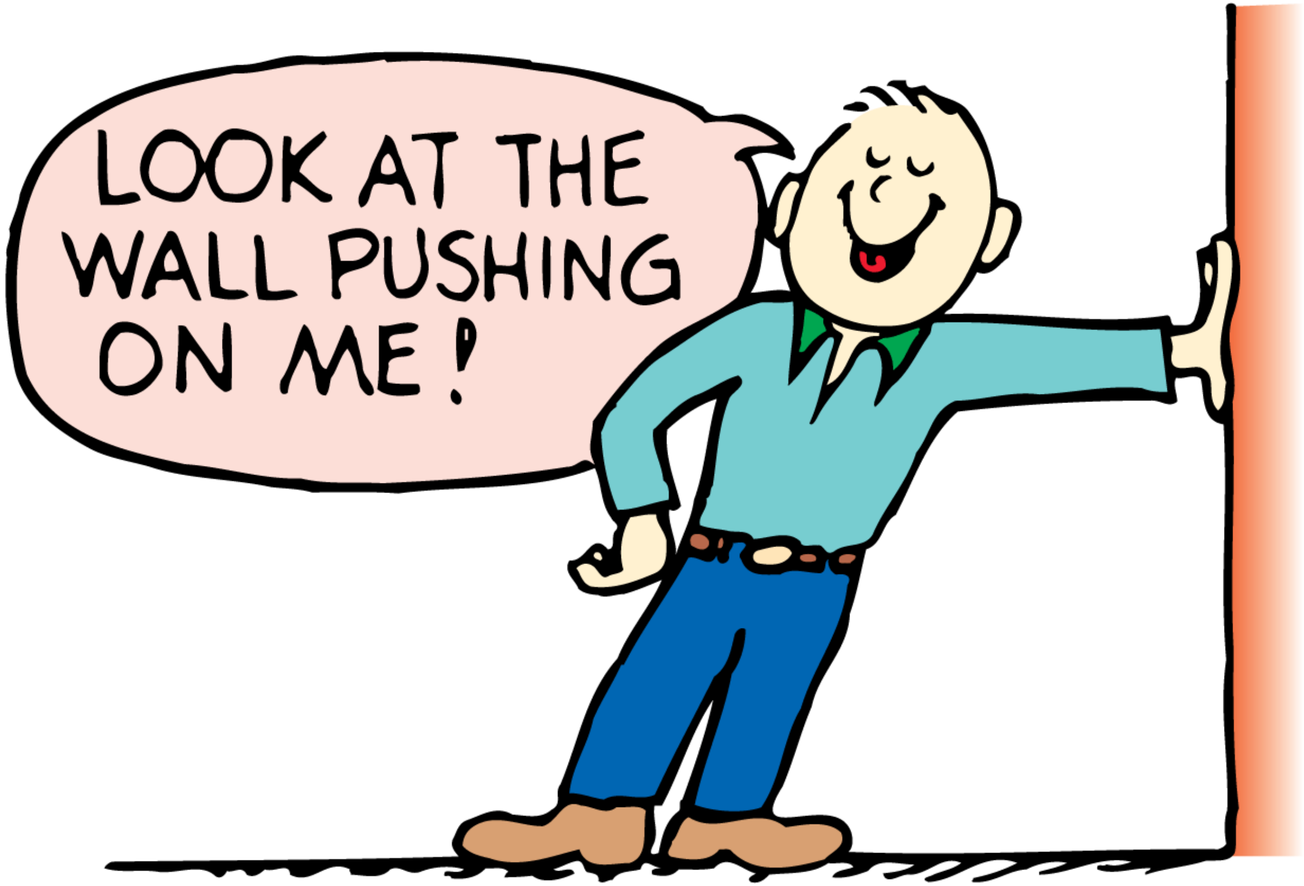
Mass and weight

- The *weight* of an object (on the earth) is the gravitational force that the earth exerts on it.
- The weight W of an object of mass m is

$$W = mg$$

- The value of g depends on altitude.
- On other planets, g will have an entirely different value than on the earth.

When you push on the wall, the wall pushes on you.



Newton's Third Law of Motion Law of Action - Reaction

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

Examples: skater leans on wall

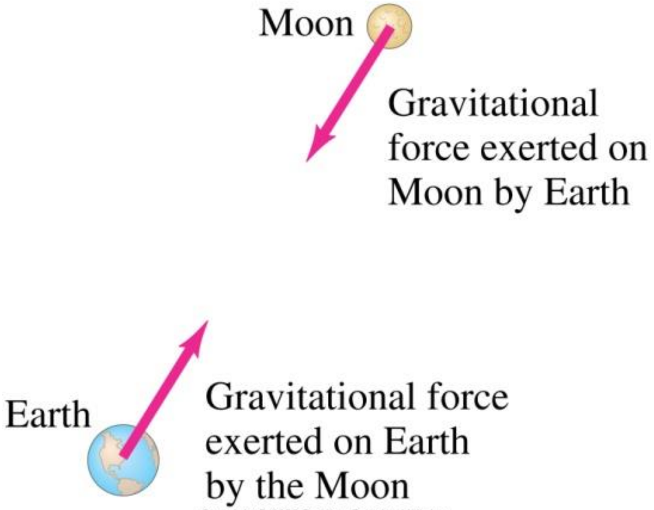
→wall exerts an equal but opposite

force on skater

Earth exerts a force on moon

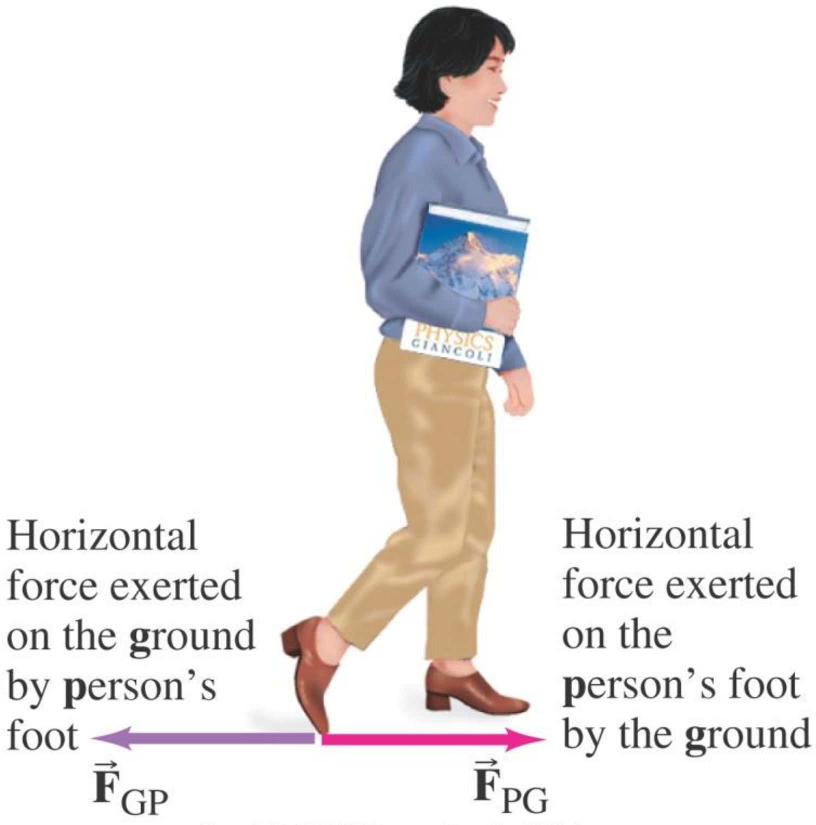
→moon exerts equal but opposite

force on earth



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

Is important to realize that these forces act on different things and thus they don't cancel.



Newton’s third law describes the relationship between two forces in an interaction.

- One force is called the **action force.**
- The other force is called the **reaction force.**
- Neither force exists without the other.
- They are equal in strength and opposite in direction.
- They occur at the same time (simultaneously).

Newton’s third law is often stated: ***“To every action there is always an equal opposing reaction.”***

It doesn’t matter which force we call *action* and which we call *reaction*.

In every interaction, the forces always occur in pairs.

- *You push against the floor, and the floor simultaneously pushes against you.*
- *The tires of a car interact with the road to produce the car’s motion. The tires push against the road, and the road simultaneously pushes back on the tires.*
- *When swimming, you push the water backward, and the water pushes you forward.*

Lift

Using Newton's third law, we can understand how a helicopter gets its lifting force.

- The whirling blades force air particles downward (action).
- The air forces the blades upward (reaction).
- This upward reaction force is called lift.
- When lift equals the weight of the craft, the helicopter hovers in midair. When lift is greater, the helicopter climbs upward.

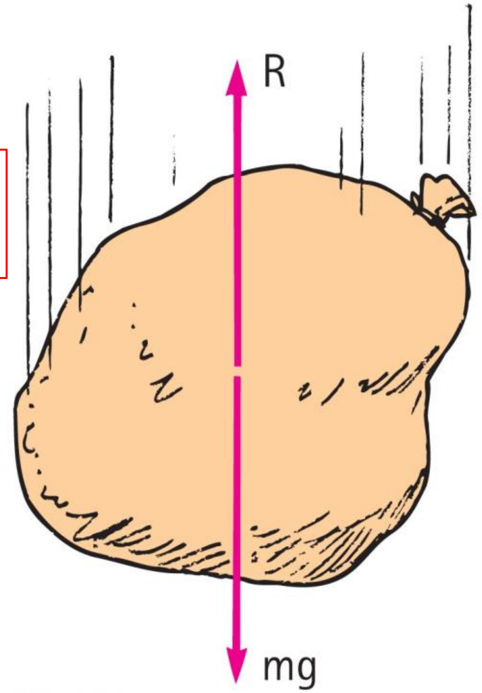
Birds and airplanes also fly because of action and reaction forces. When a bird is soaring, the shape of its wings deflects air downward. The air in turn pushes the bird upward.
The slightly tilted wings of an airplane also deflect oncoming air downward and produce lift.

When Acceleration Is Less than g --Nonfree Fall

How do Newton's law apply to objects falling air?

- When an object falls downward through the air it experiences
  - force of gravity(mg) pulling it downward.
  - air drag force (R) acting upward.

$$\boxed{a = \frac{F_{net}}{m} = \frac{mg - R}{m}}$$



Important thing to keep in mind is net force. In cases air resistance is ignored the net force is only due to gravity.

<u>The condition of nonfree fall:</u>

- occurs when air resistance is non-negligible.
- depends on two things:

- **Applications of Newton's Laws**

- **Giancoli, Sec 4-6 → 4-7**

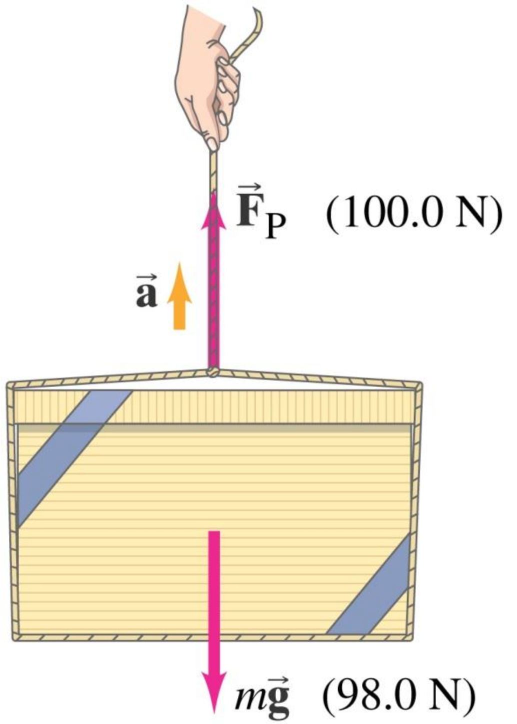
Galileo told us that all objects experience an acceleration due to gravity of *g* and Newton gave us ***F* = *ma*.** We can combine these to ideas to realize that the weight of an object is the force of attraction that the earth exerts on objects and it can be written

$$\boxed{\vec{F}_G = m\,\vec{g}}$$

It should be noted that weight is a force and thus the proper (SI) units **are newtons (N) or pounds(this is not SI unit)**. It is technically incorrect to say that something weights 2.0 kg because that is the mass of the object.

Application: Ropes

Tension: when the man pulls on the rope, the tension in the rope transmits the force to the box. The tension is 100 N which exerts a 100 N force upward on the box and a 100 N downward force on the hand.



$\vec{F}_P$

$m\vec{g}$

$$m = \frac{98\ N}{9.8\, m/s^2} = 10\ kg$$

$$\sum F_y = ma_y$$

$$F_p - mg = ma$$

$$100\ N - 98\ N = (10\ kg)\,a$$

$$a = 0.20\ m/s^2$$

Steps in Solving Problems

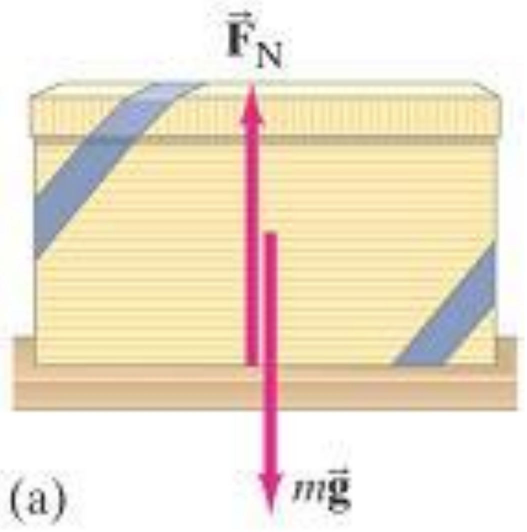
1. Draw free-body diagram for every object that is ”free”
2. Select coordinate system such that one of the axis is along the direction of acceleration
3. Write out the equations of motion for the *x* and *y* coordinate:

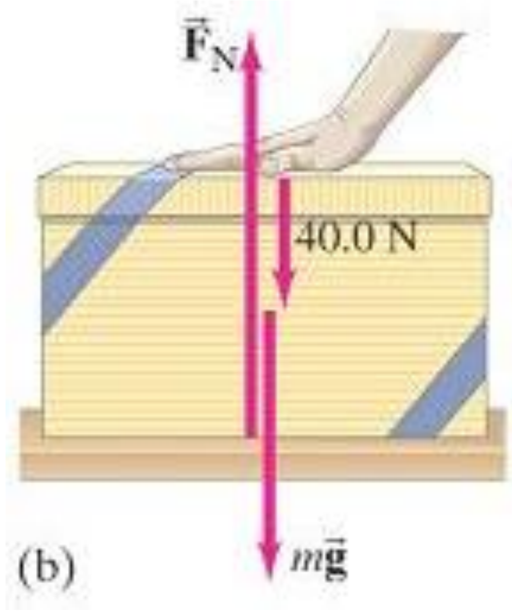
$$\sum F_x = ma_x$$

$$\sum F_y = ma_y$$

4. Step 2 should guarantee that the sum of the forces in all but one direction equals zero.
5. Solve the equations simultaneously

Application: Normal Force





When a box rests on a table, the table must exert enough upward force to support the box, otherwise, the table will collapse. This upward force is called the normal force $\mathbf{F_N}$ because it is normal to the surface.

When we push down with a force of 40 N the normal force will increase by 40 N.

The force exerted perpendicular to a surface is called the normal force. It is exactly as large as needed to balance the force from the object. (If the required force gets too big, something breaks!)

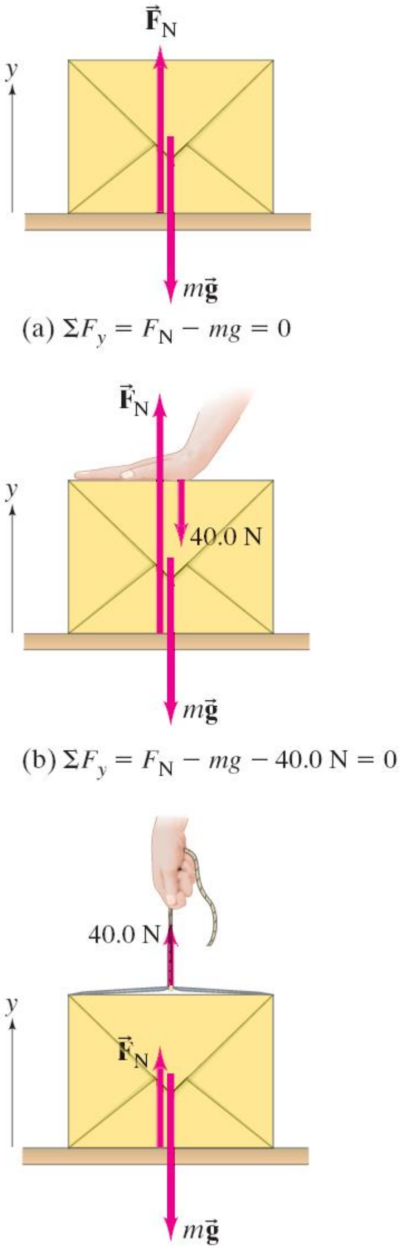
Example 4-6: Weight, normal force, and a box.

A friend has given you a special gift, a box of mass 10.0 kg with a mystery surprise inside. The box is resting on the smooth (frictionless) horizontal surface of a table.

(a) Determine the weight of the box and the normal force exerted on it by the table.

(b) Now your friend pushes down on the box with a force of 40.0 N. Again determine the normal force exerted on the box by the table.

(c) If your friend pulls upward on the box with a force of 40.0 N, what now is the normal force exerted on the box by the table?



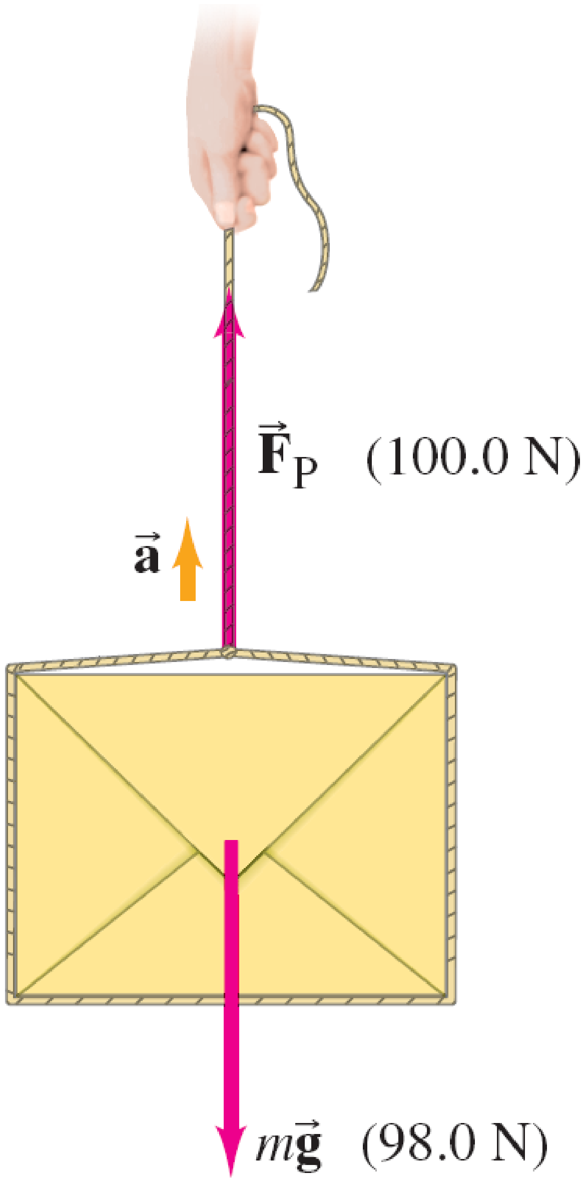
(a) $\Sigma F_y = F_N - mg = 0$

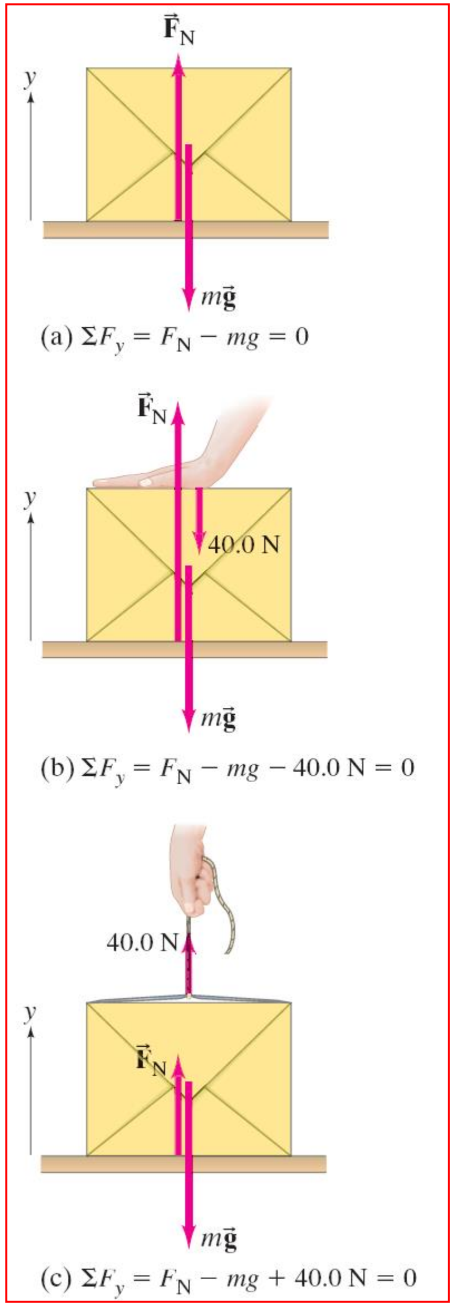
(b) $\Sigma F_y = F_N - mg - 40.0\ \text{N} = 0$

(c) $\Sigma F_y = F_N - mg + 40.0\ \text{N} = 0$

Example 4-7: Accelerating the box.

What happens when a person pulls upward on the box in the previous example with a force greater than the box's weight, say 100.0 N?





Free-Body Diagrams *A diagram showing all the forces acting on an object is called a **free-body diagram***

- Essential part of solution
- Vital tool to understand problem
- Forces are the only vectors on free-body diagrams
- If there are two objects, each of them will have a free-body diagram
- If there are two objects, label each mass properly: m_1 and m_2
- Select a coordinate system such that the acceleration direction is along one axis
- Then apply Newton's Second Law (two equations for each object):