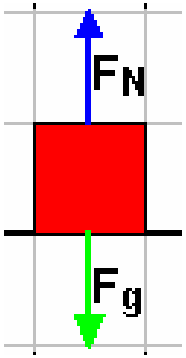
Free-body Diagrams

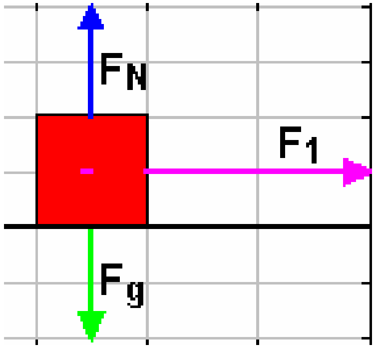
To help us understand why something moves as it does (or why it remains at rest) it is helpful to draw a free-body diagram. The free-body diagram shows the various forces that act on an object.

A Question about free-body diagrams

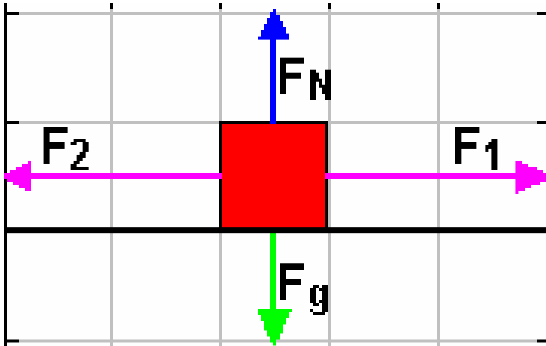
An object remains at rest on a table. Which free-body diagram(s) of the object match(es) this motion?



1. Force of gravity directed down, normal force from the table directed up.



2. Force of gravity down, normal force up, and some other force directed to the right.



3. Force of gravity down, normal force up, and equal-and-opposite forces directed left and right.
4. It could be either 1 or 3.

Question 2 about free-body diagrams

An object moves at constant velocity to the right across a table. Which free-body diagram(s) of the object match(es) this motion?

1. Force of gravity directed down, normal force from the table directed up.
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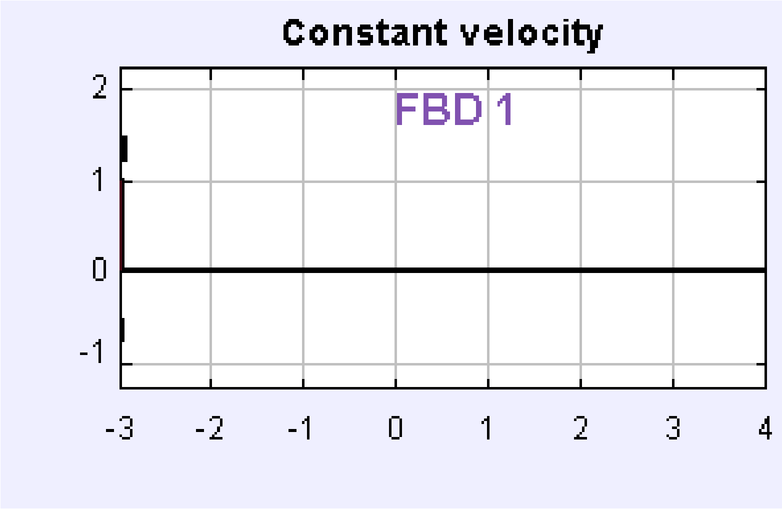

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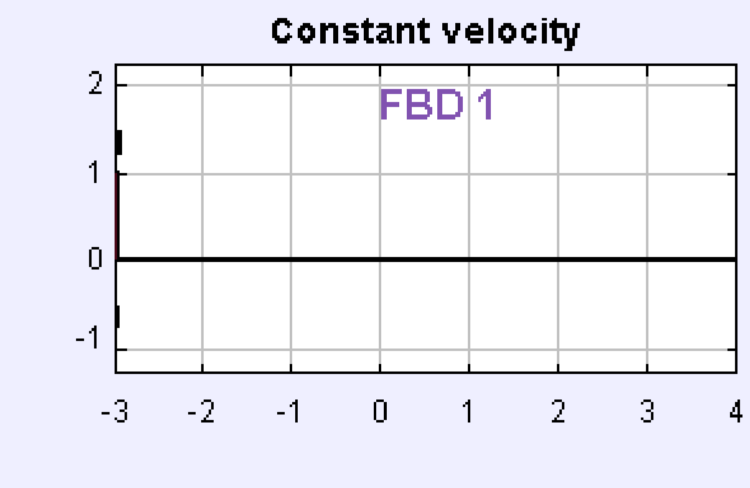

Worksheet, part 1

Define force.

Force

A force is a push or a pull.

A force is a vector, so it has a direction associated with it.

Forces are associated with interactions between objects. If you sit on a chair there is an interaction between you and the chair; the chair exerts a force on you and you exert a force on the chair. Forces always come in pairs.

The MKS unit of force is the newton (N).

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

The Force of Gravity

The force of gravity is an example of a force that exists between objects without them having to be in contact.

The force of gravity exerted by one object (like the Earth) on another object, like an apple, is proportional to the mass of the apple. The direction of the force is toward the object applying the force.

At the Earth's surface the gravitational force exerted on an object of mass m by the Earth has a magnitude mg and is directed down.

Worksheet, part 2

Sketch two free-body diagrams for two objects, one with three times the mass of the other, as the objects fall.

Answer the two questions below the free-body diagrams.

Dropping two objects

The mass of a baseball is about 2.5 times larger than that of a tennis ball. When they are released simultaneously from rest from the same height, which ball reaches the ground first?

1. The baseball.
2. The tennis ball.
3. Neither – they reach the ground at the same time.

Changing the rules

Do we get the same result when we drop a piece of paper and a textbook? Why or why not?

Connecting force and motion

The net force (the vector sum of all the forces) acting on an object is directly connected to the object's ___________?

Position?

Velocity?

Acceleration?

Connecting force and motion

The net force (the vector sum of all the forces) acting on an object is directly connected to the object's acceleration.

Worksheet, part 3

See if you know what Newton's Second Law is.

If so, apply it to find the acceleration of an object in free fall.

Newton’s Second Law

Newton's second law states that the acceleration of an object is proportional to the net force acting on that object and inversely proportional to the mass of the object.

Newton's Second Law: $\vec{a} = \dfrac{\Sigma\vec{F}}{m}$

$\Sigma\vec{F}$ represents the net force – the vector sum of all the forces acting on the object.

An object in free fall

The free-body diagram shows only one force acting on the object. This force is the force of gravity, mg, directed down.

Newton's Second Law: $\vec{a} = \dfrac{\Sigma \vec{F}}{m}$

$$\Sigma \vec{F} = m\vec{g}$$

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$$\Sigma\vec{F} = m\vec{g}$$

$$\vec{a} = \frac{m\vec{g}}{m} = \vec{g} = 9.8 \text{ m/s}^2, \text{ directed down.}$$

Worksheet, part 4

On the back of the worksheet, sketch free-body diagrams for the four different situations.

Think about whether the diagrams are consistent.

Worksheet, part 5

Do you know what Newton’s First Law says? If so, write it on the worksheet.

Newton’s First Law

An object at rest tends to remain at rest, and an object in motion tends to remain in motion with a constant velocity (constant speed and direction of motion), unless it is acted on by a nonzero net force.

Rules of thumb

When drawing a free-body diagram, think about:

1. What applies each of the forces you drew?

2. Considering the object’s motion, is the overall free-body diagram consistent with Newton’s Laws ?

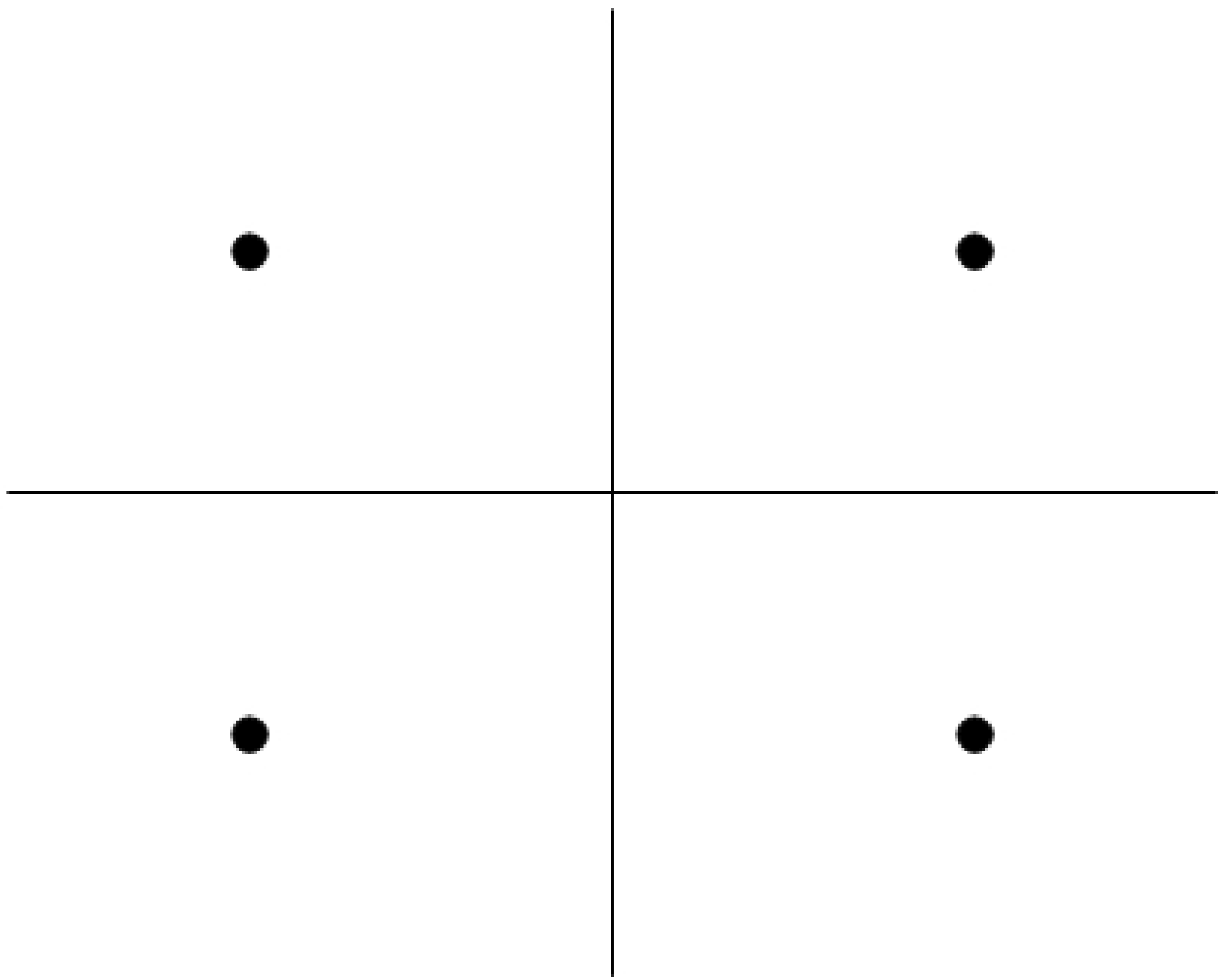
Check your four free-body diagrams again.

Hint: all four free-body diagrams should be consistent with each other. Outer space

Worksheet

Let’s work on drawing the free-body diagrams, on the back of the worksheet.

Drawing the free-body diagrams



“At rest” is a special case of constant-velocity motion

As far as forces and free-body diagrams are concerned, there is no difference between an object remaining at rest and an object traveling at constant velocity.

Question 2 about free-body diagrams

An object moves at constant velocity to the right across a table. Which free-body diagram(s) of the object match(es) this motion?

1. Force of gravity directed down, normal force from the table directed up.
2. Force of gravity down, normal force up, and some other force directed to the right.
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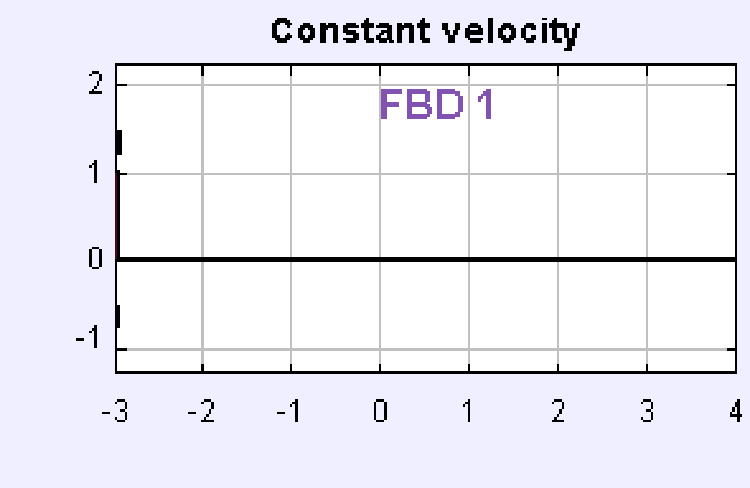
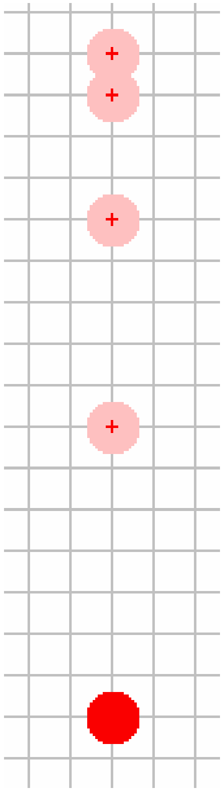
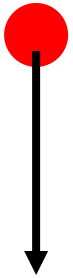


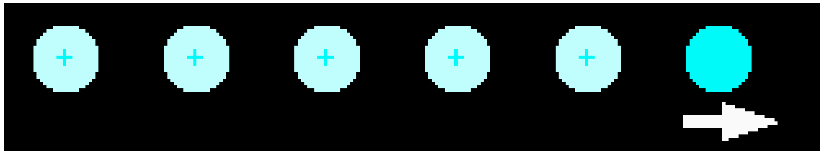
From last time



Here's a free-body diagram for an object experiencing free fall. The free-body diagram shows a constant downward force.



Many of us did a similar free-body diagram for the object drifting to the right in outer space, and the hockey puck.



Is there an inconsistency here?

Worksheet

Do you know what Newton’s First Law says? If so, write it on the worksheet.

Newton's First Law

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Newton’s First Law

An object at rest tends to remain at rest, and an object in motion tends to remain in motion with a constant velocity (constant speed and direction of motion), unless it is acted on by a nonzero net force.

<u>What this means</u>

As far as forces and free-body diagrams are concerned, there is no difference between an object remaining at rest and an object traveling at constant velocity.

Rules of thumb

When drawing a free-body diagram, think about:

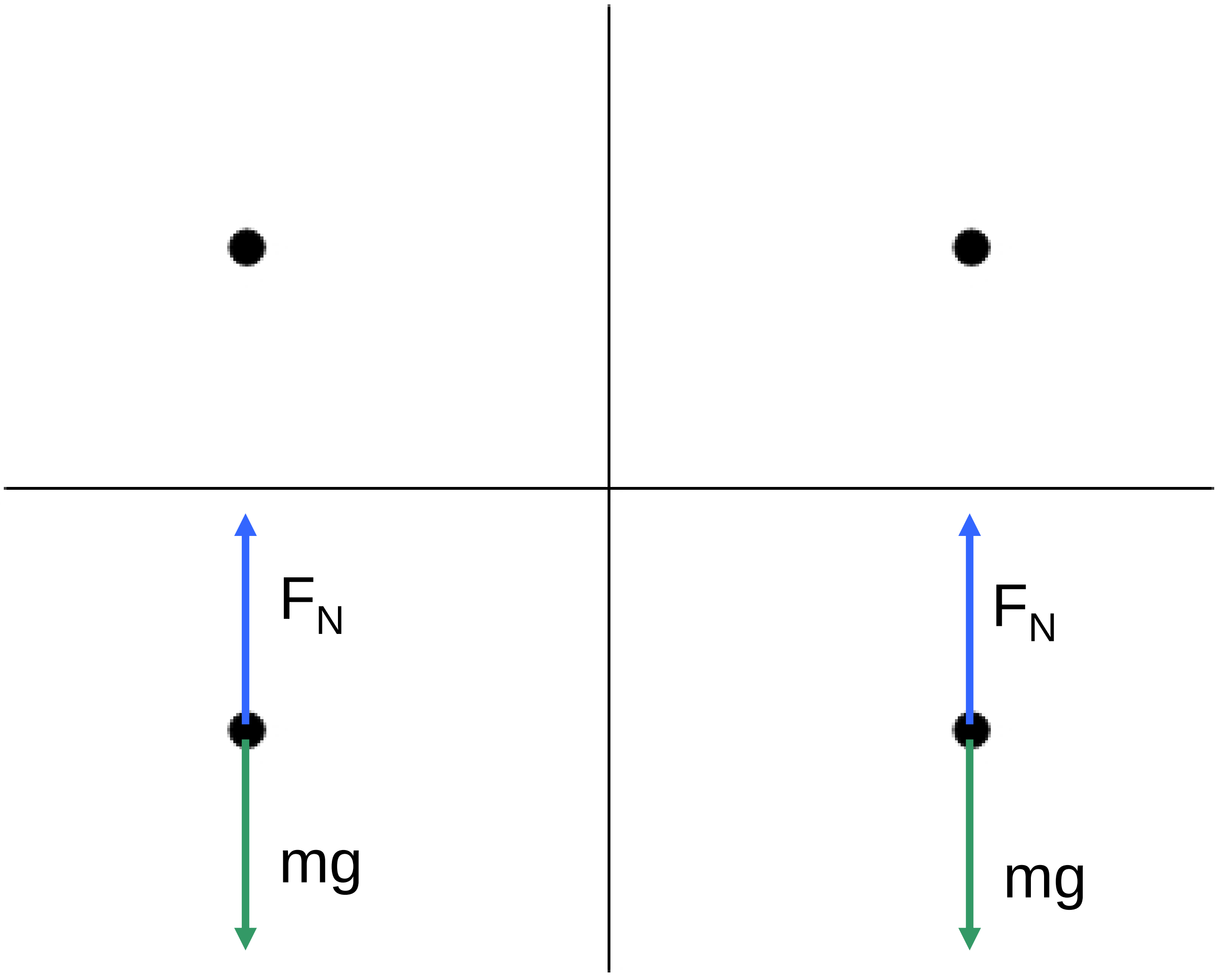
1. What applies each of the forces you drew?

2. Considering the object’s motion, is the overall free-body diagram consistent with Newton’s Laws ?

Check your four free-body diagrams again.

Hint: all four free-body diagrams should be consistent with each other.

The four diagrams



Force

Previously, we said:

Forces always come in pairs.

Based on your experience with the Forces between Carts experiment, modify this statement to make it stronger.

Newton’s Third Law

Forces always come in equal-and-opposite pairs.

Newton’s Third Law: When one object exerts a force on a second object, the second object exerts a force of equal magnitude, in the opposite direction, on the first object.

The Force of Tension

Tension is a force applied by a string or a rope. This force is usually labeled T or F_T **.**

We usually assume that a rope has no mass, and does not stretch.

You can't push with a rope! The tension force always goes along a string or rope away from the object attached to it.

The Normal Force

The normal force is one component of the contact force between objects, the other component being the frictional force. The normal force is usually symbolized by *N* or F_N .

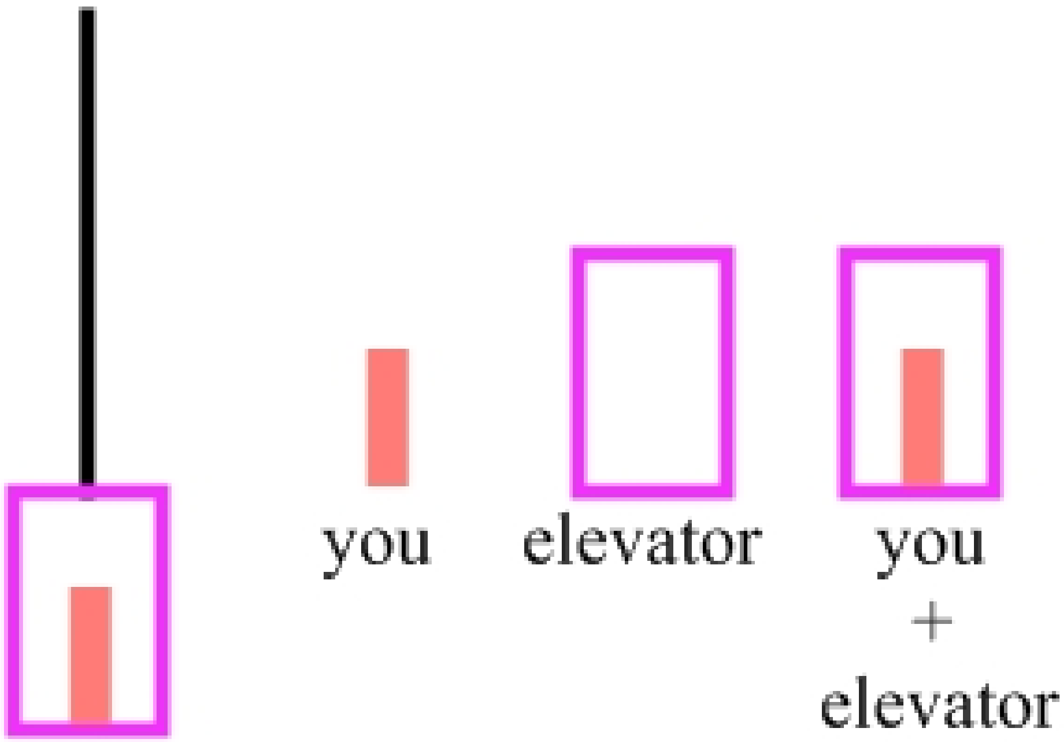
The normal force is perpendicular to the surfaces in contact.

Objects lose contact with one another when the normal force goes to zero.

The normal force is the force that would be measured by a scale placed between the objects in contact.

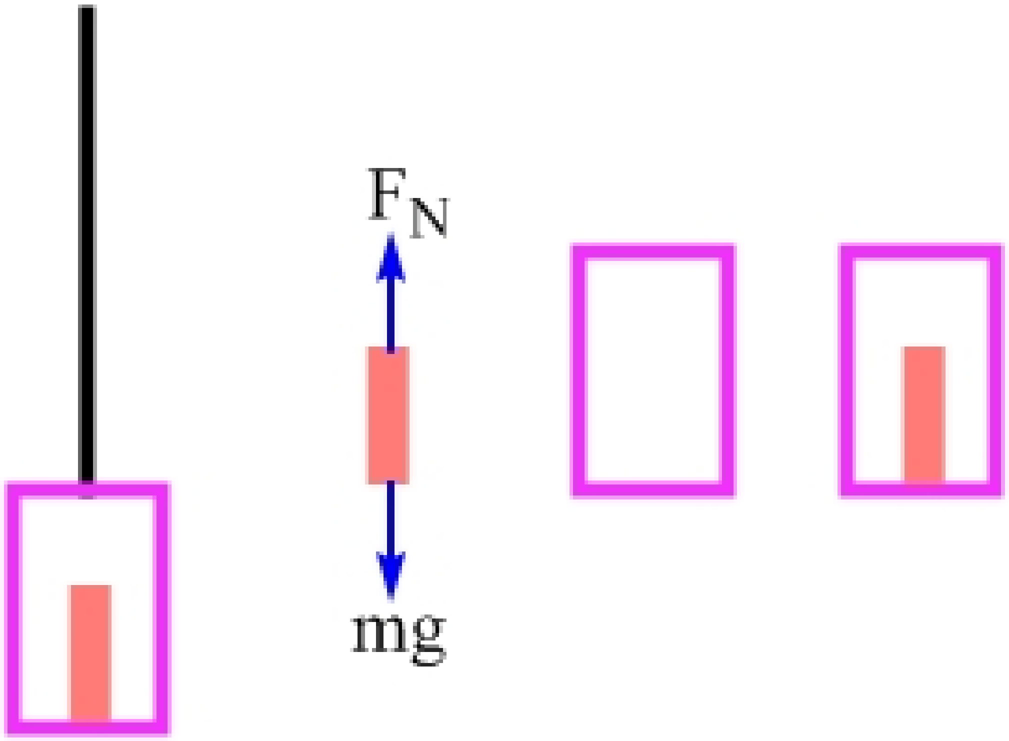
Worksheet – Elevator Physics

Sketch three free-body diagrams, for the situation of you inside an elevator, with the whole system at rest.



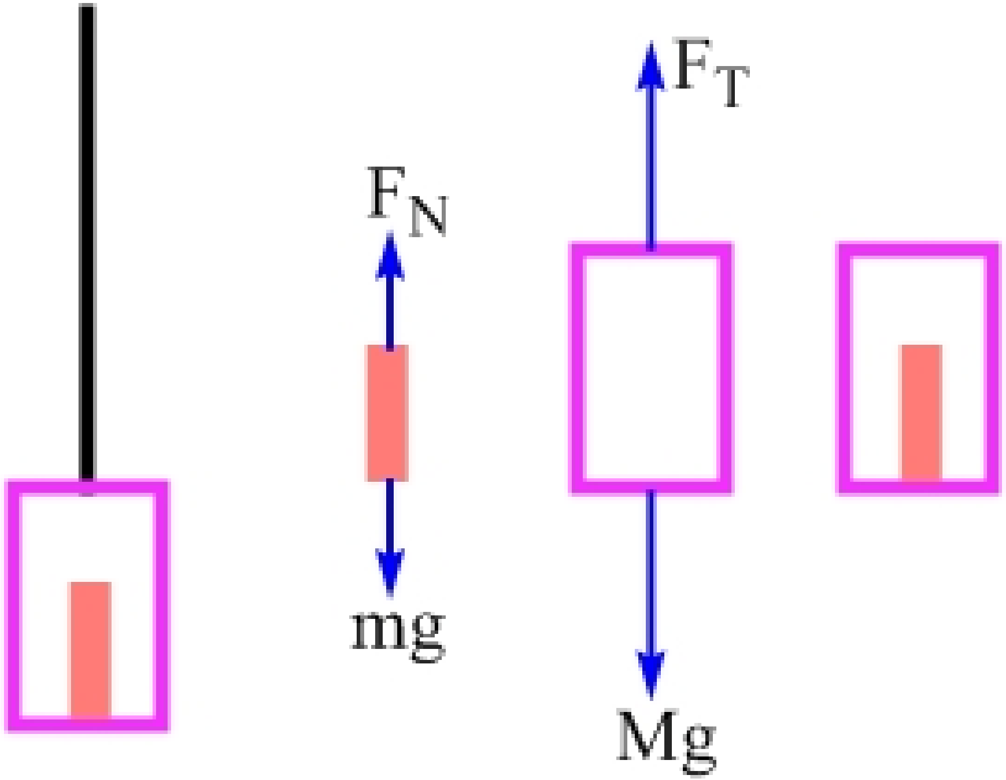
Worksheet – Elevator Physics

One student's free-body diagram of you, for this situation.



Worksheet – Elevator Physics

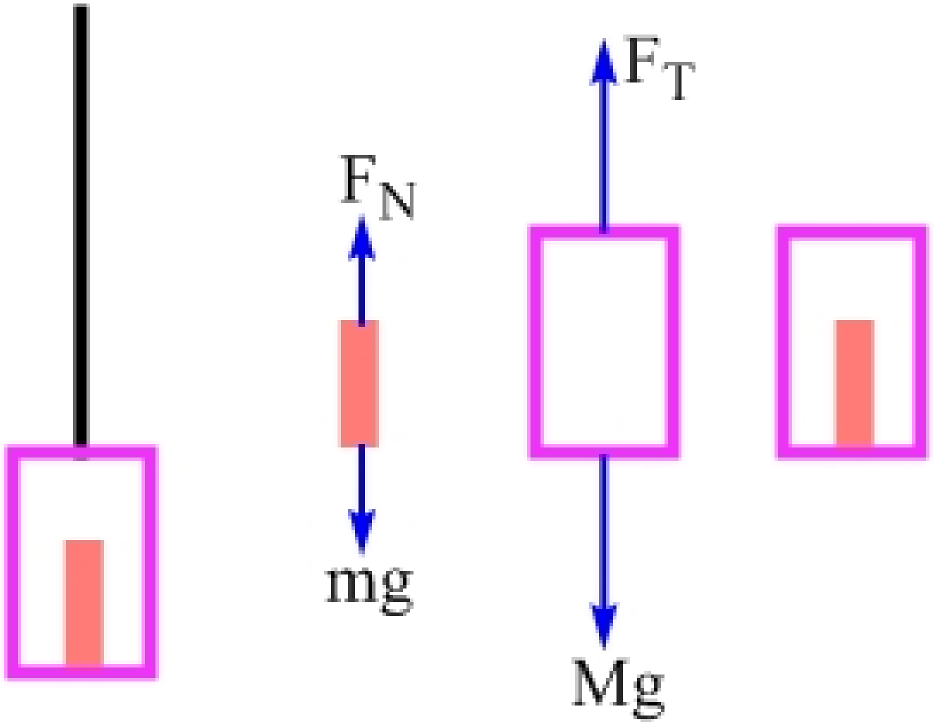
One student's free-body diagram of the elevator, for this situation.



Free-body diagram of the elevator

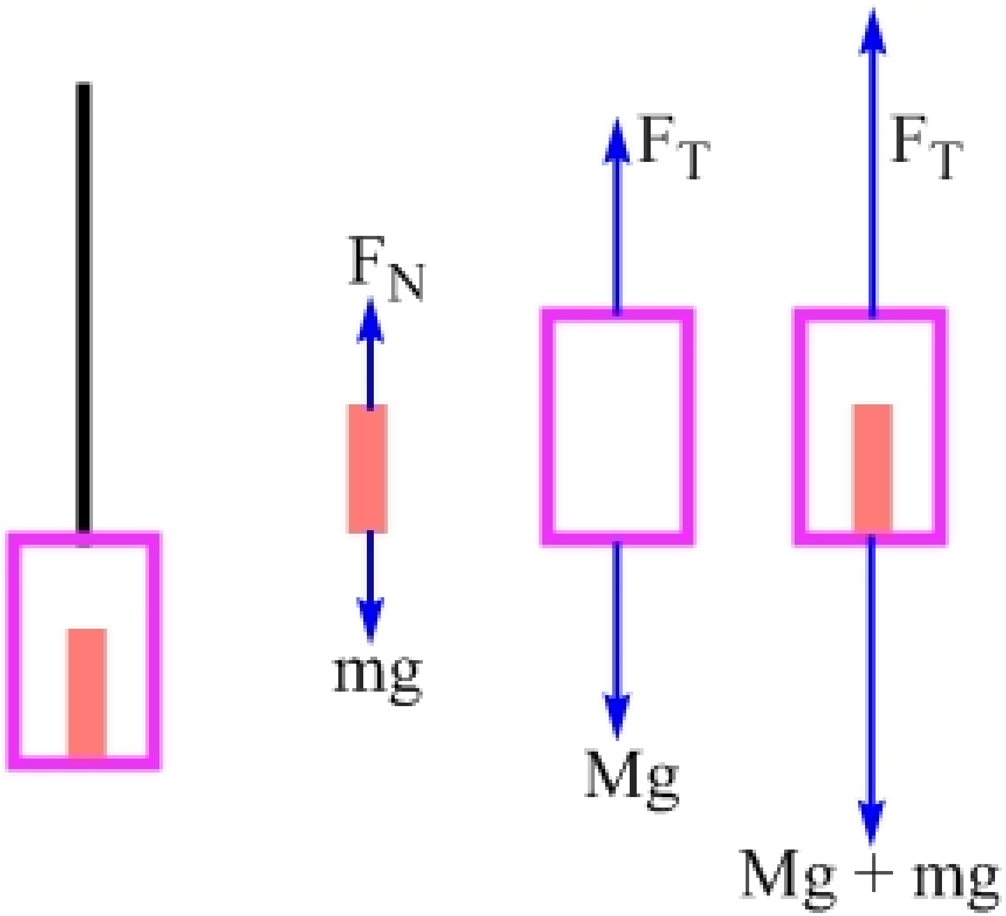
Our free-body diagram of the elevator alone shows an upward force of tension, applied by the cable on the elevator, and a downward force of gravity, applied by the Earth on the elevator. Is this free-body diagram complete?

1. Yes.
2. No.



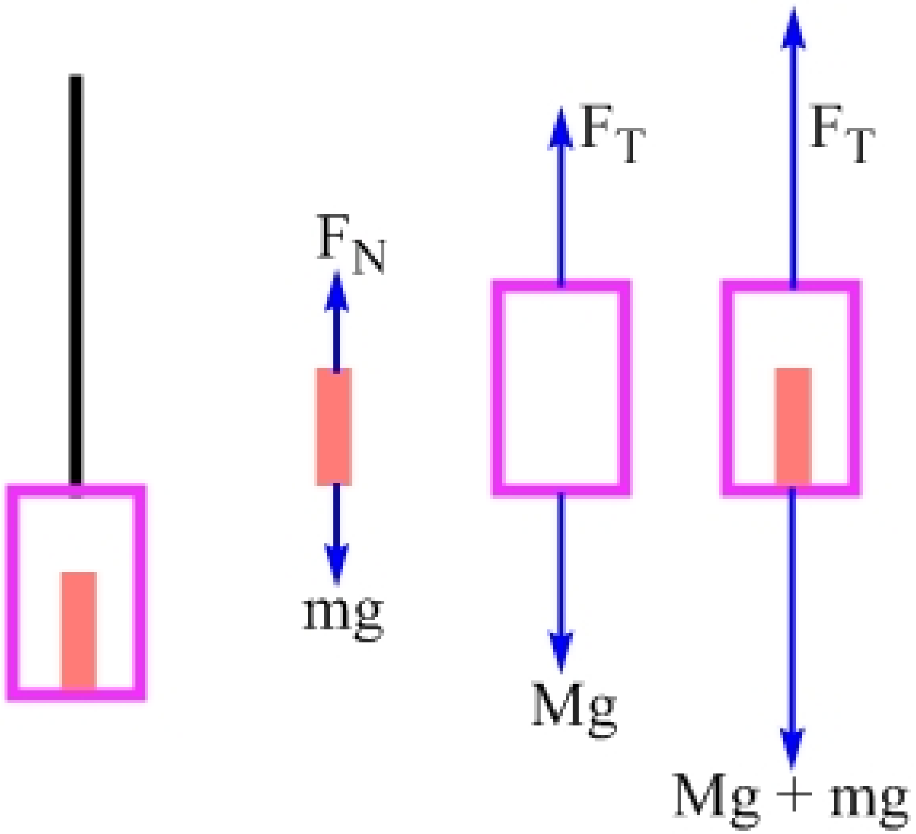
Worksheet – Elevator Physics

One student's free-body diagram of the you + elevator system, for this situation.



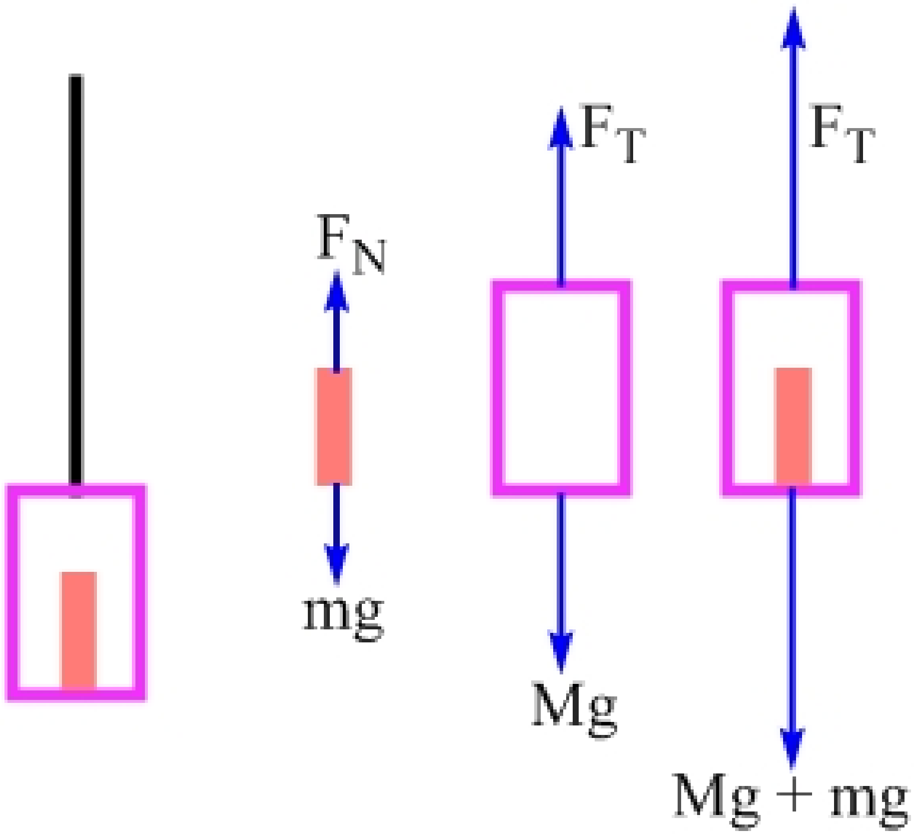
Checking our work

What is the tension in the cable, according to the free-body diagram of the elevator? What is it according to the free-body diagram of the system of you plus the elevator?



Correcting our work

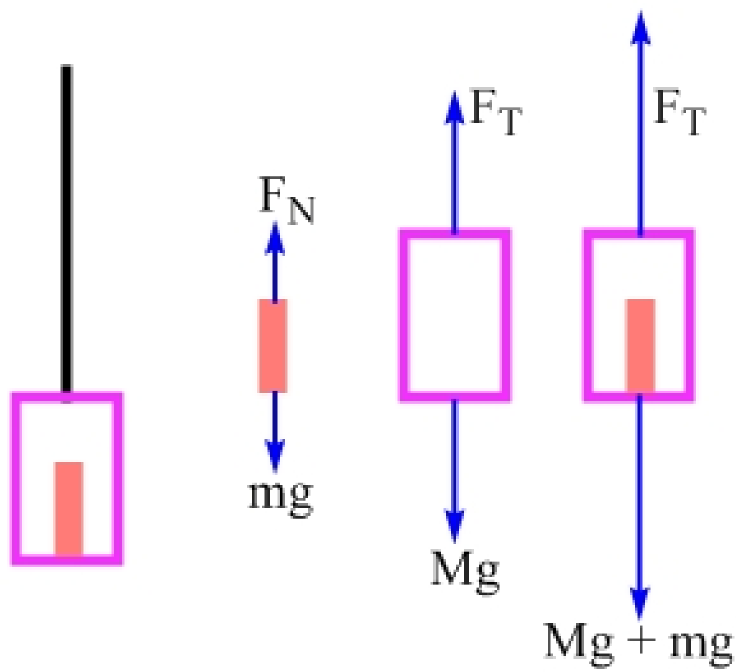
We should get one answer for the tension in the cable, so we need to fix one of our diagrams. Which?



Fixing the elevator’s free-body diagram

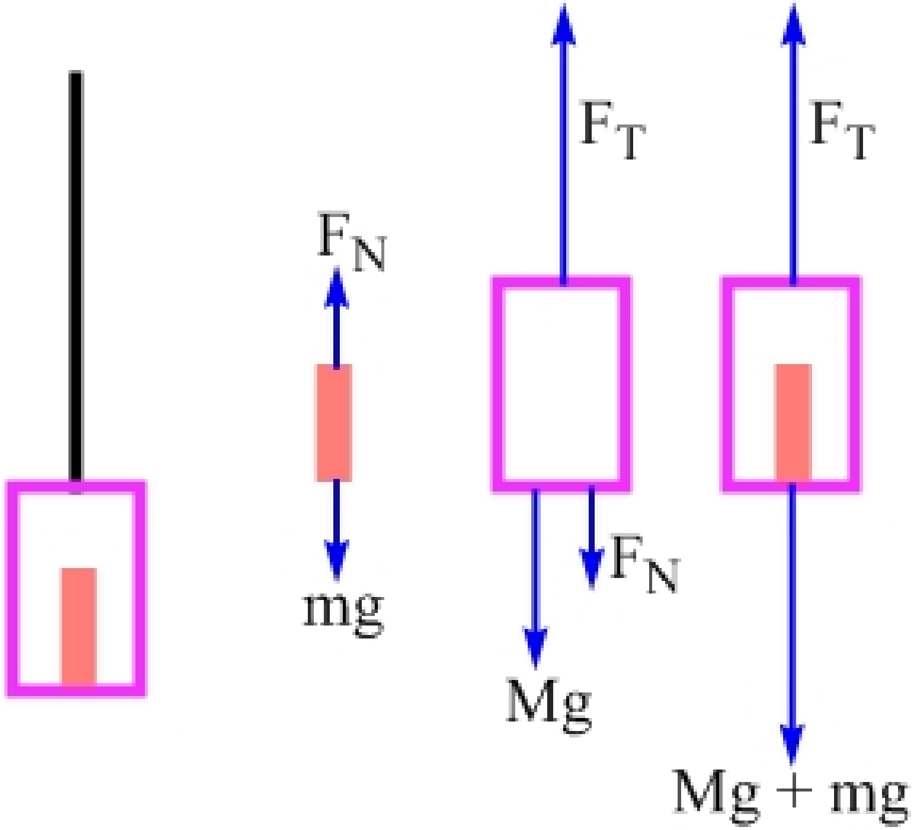
What should we add to the elevator’s free-body diagram to fix the problem?

1. A downward force of gravity, mg.
2. A downward normal force, applied by you on the elevator.
3. Either of the above, it doesn’t matter.



Forces that belong on a free-body diagram

Only forces that are being applied to the object should appear on that object's free-body diagram. We should add a downward normal force, applied to the elevator by you.



Forces that belong on a free-body diagram

Only forces that are being applied to the object should appear on that object's free-body diagram.

We should add a downward normal force, applied to the elevator by you.

Yes, *mg* is numerically equal to this normal force in this case. When the system has an acceleration, however, these forces are no longer equal.

The system has a constant velocity directed up

When the system of you and the elevator is moving up with a constant velocity, what do we need to change on the free-body diagrams?

1. An extra force, directed up, needs to be added to each free-body diagram.
2. One or more of the existing forces needs to change in magnitude.
3. No changes are necessary.

Constant velocity

No changes are required – the forces must still all balance.

The system has a constant acceleration directed up

When the system of you and the elevator has a constant acceleration directed up, what do we need to change on the free-body diagrams?

1. An extra force, directed up, needs to be added to each free-body diagram.
2. One or more of the existing forces needs to change in magnitude.
3. No changes are necessary.

Constant acceleration

In this case, each free-body diagram needs to show a net force directed up. This is achieved by making appropriate adjustments to the tension in the cable, and the normal force associated with the interaction between you and the elevator.

Two boxes

You accelerate a system of two boxes to the right by pushing on the green box with a 15 N force directed right. The green box has a larger mass than the blue box. Sketch the three free-body diagrams asked for on the worksheet. The boxes are on a frictionless table.

Which box applies a larger force to the other?

Consider magnitudes of forces only.

1. The green box applies more force to the blue box than the blue box applies to the green box.
2. The blue box applies more force to the green box than the green box applies to the blue box.
3. The green box applies a force to the blue box that has the same magnitude as the force the blue box applies to the green box.

Newton’s Third Law!!!

Which box experiences a larger net force?

The two boxes accelerate as one unit.

1. The green box experiences a larger net force.
2. The blue box experiences a larger net force.
3. The net forces are equal.

Apply Newton's Second Law

The net force is equal to the product of the mass multiplied by the acceleration.

How do the accelerations compare?

How do the masses compare?

Apply Newton's Second Law

The net force is equal to the product of the mass multiplied by the acceleration.

How do the accelerations compare?

The boxes have the same acceleration.

How do the masses compare?

Apply Newton's Second Law

The net force is equal to the product of the mass multiplied by the acceleration.

How do the accelerations compare?

The boxes have the same acceleration.

How do the masses compare?

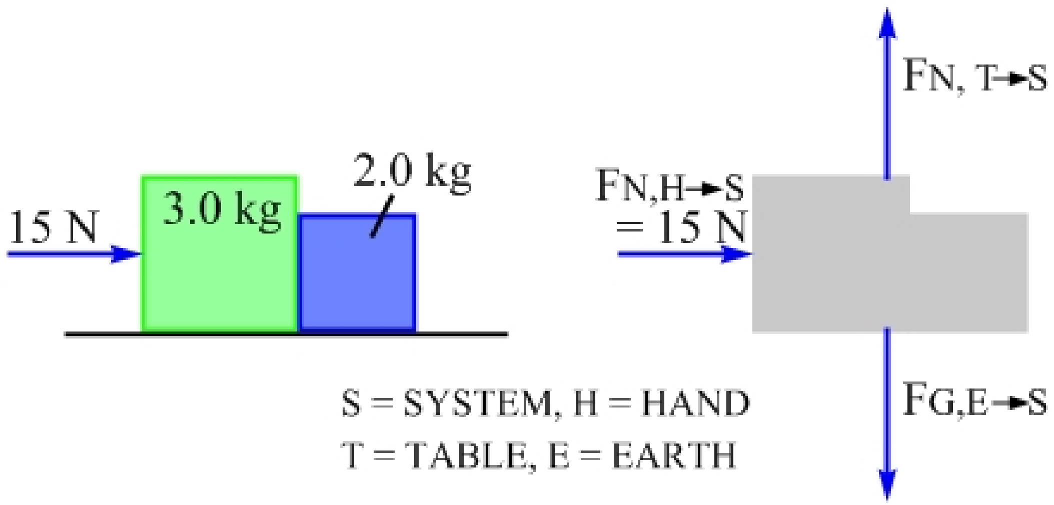
The green box has a larger mass.

Find the acceleration of the system

Let’s choose positive to be to the right.

Which of the three free-body diagrams should we use?

Find the acceleration



The simplest is the free-body diagram of the two-box system. Apply Newton's Second Law.

$$\sum \vec{F} = (m_G + m_B)\vec{a}$$

The vertical forces cancel, so we can neglect them.

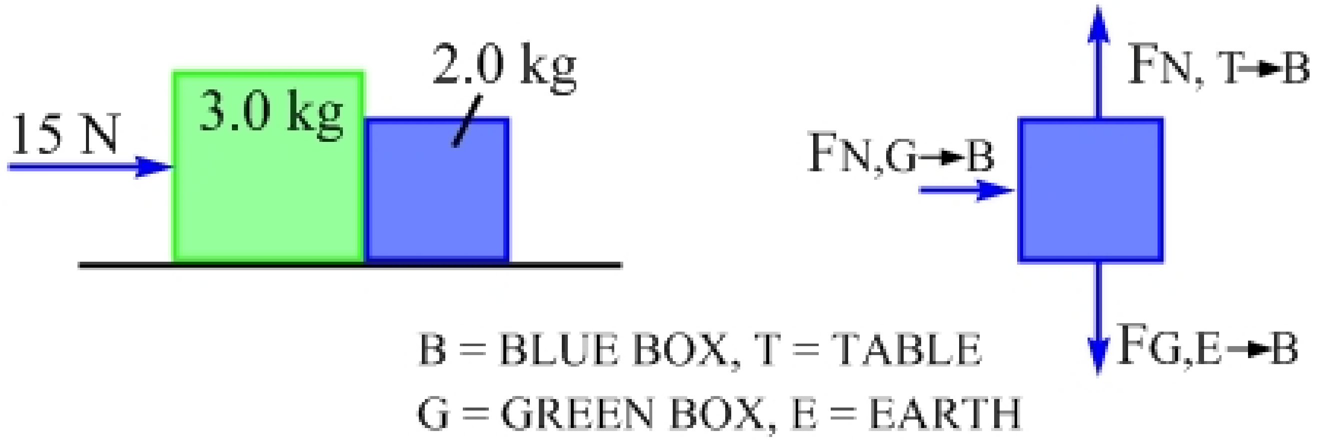
$$\vec{a} = \frac{\sum \vec{F}}{(m_G + m_B)} = \frac{+15\ \text{N}}{5.0\ \text{kg}} = +3.0\ \text{m/s}^2$$

Find the force the green box applies to the blue box.

Which free-body diagram should we use?

Find the force the green box applies to the blue box.

Let's use the free-body diagram of the blue box.



Apply Newton's Second Law.

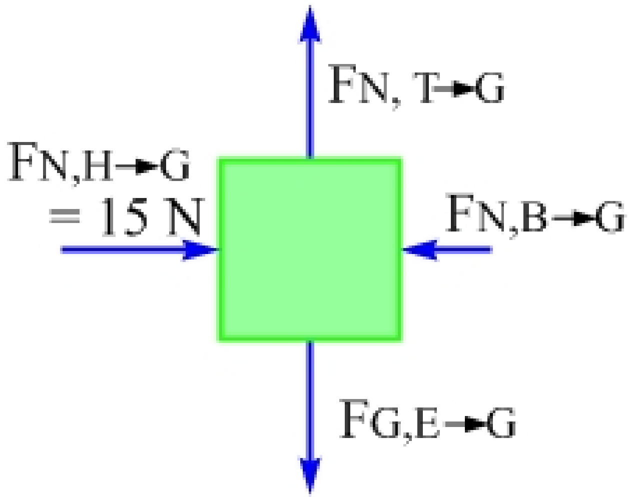
$$\sum \vec{F} = m_B\,\vec{a} = 2.0\text{ kg} \times (+3.0\text{ m/s}^2) = +6.0\text{ N}$$

The vertical forces cancel, so the net force is the force the green box applies to the blue box, 6.0 N to the right.

Find the force the blue box applies to the green box.

Which free-body diagram should we use?

Find the force the blue box applies to the green box.



In this case, let's use the

free-body diagram of the green box.

Apply Newton's Second Law.

$$\sum \vec{F} = m_B \, \vec{a} = 3.0 \text{ kg} \times (+3.0 \text{ m/s}^2) = +9.0 \text{ N}$$

The vertical forces cancel, and the net force is the vector sum of the 15 N force directed right, and the force the blue box exerts to the left.

$$+15.0 + \vec{F}_{N,B \to G} = +9.0 \text{ N}$$

$$\vec{F}_{N,B \to G} = +9.0 \text{ N} - 15.0 \text{ N} = -6.0 \text{ N}$$

This agrees with Newton's Third Law.

Whiteboard