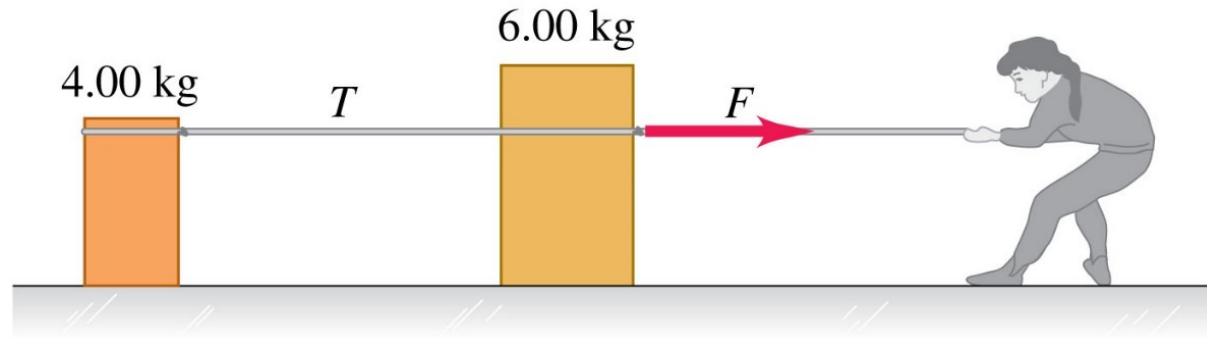


Example:

A woman pulls on a 6.00-kg crate, which in turn is connected to a 4.00-kg crate by a light rope. The light rope remains taut.



Compared to the 6.00-kg crate, the lighter 4.00-kg crate

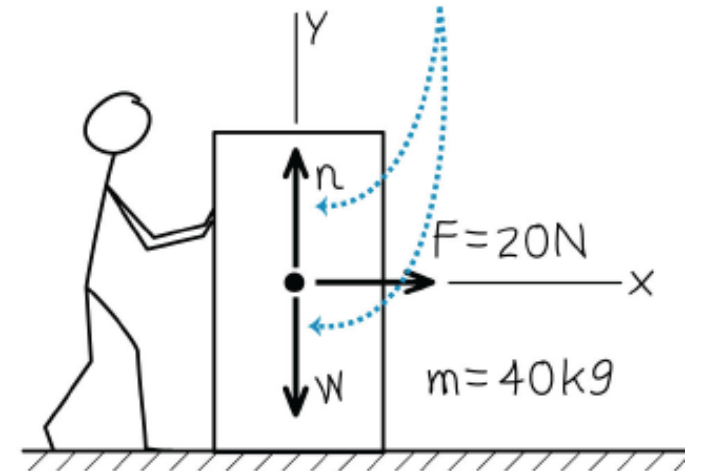
- A. is subjected to the same net force and has the same acceleration.
- B. is subjected to a smaller net force and has the same acceleration.
- C. is subjected to the same net force and has a smaller acceleration.
- D. is subjected to a smaller net force and has a smaller acceleration.

More about Newton's second law

- You must be certain about which body we are applying it to
- \vec{F}_{net} must be the vector **sum of all the forces** that act on that body
- Only forces that act on that body are to be included in the vector sum
- Acceleration along an axis is determined by the net force component along the same axis.

$$F_{net,x} = ma_x \qquad F_{net,y} = ma_y$$

$F_{net} = ma$ is the resultant net force, do not include it in the sum of forces.



Example: Newton's second law

Three horizontal ropes pull on a stone (mass: 45.00 kg) on the ground, producing the vector forces \vec{A} , \vec{B} and \vec{C} . Find the **magnitude** and **direction** of **acceleration** of the stone.

$$\vec{F}_{net} = \sum \vec{F} = \vec{A} + \vec{B} + \vec{C} = m\vec{a}$$

$$A_x = +A \cos 30.0^\circ = +86.6 \text{ N}, \quad A_y = +A \sin 30.0^\circ = +50.00 \text{ N}.$$

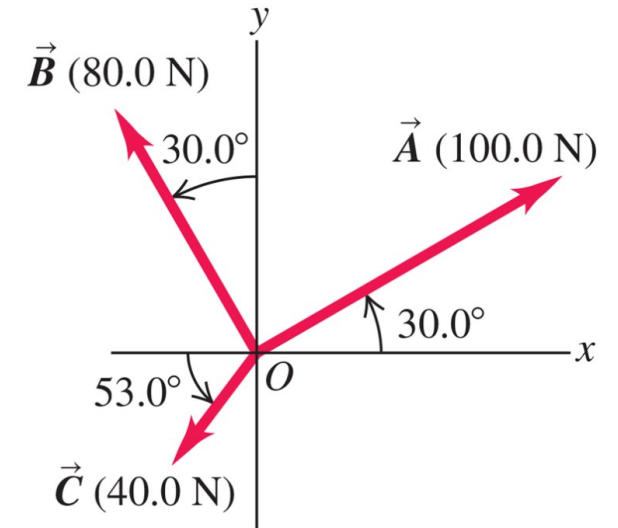
$$B_x = -B \sin 30.0^\circ = -40.00 \text{ N}, \quad B_y = +B \cos 30.0^\circ = +69.28 \text{ N}.$$

$$C_x = -C \cos 53.0^\circ = -24.07 \text{ N}, \quad C_y = -C \sin 53.0^\circ = -31.90 \text{ N}.$$

$$F_{net,x} = A_x + B_x + C_x = 22.53 \text{ N} \quad F_{net,y} = A_y + B_y + C_y = 87.34 \text{ N}$$

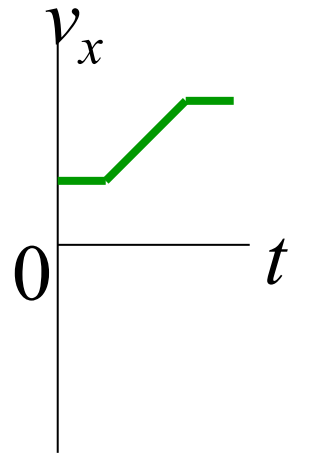
$$F_{net} = \sqrt{F_{net,x}^2 + F_{net,y}^2} = 90.2 \text{ N} \quad \vec{F}_{net} = m\vec{a} \quad |a| = |F|/m = 2 \text{ (m/s}^2\text{)}$$

$$F_{net,x} = ma_x \quad 22.53 \text{ N} = (45 \text{ kg})a_x \quad a_x = 0.5 \text{ m/s}^2$$

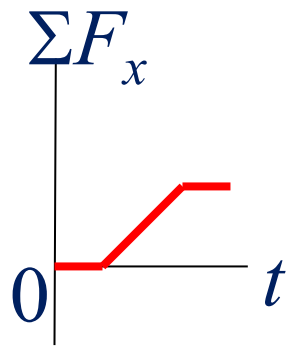


Example:

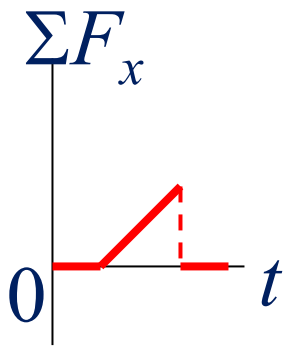
The graph to the right shows the velocity of an object as a function of time.



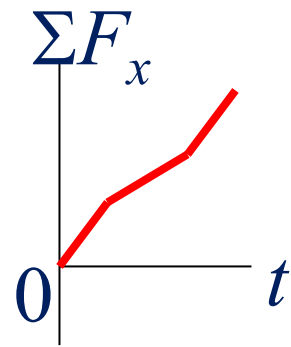
Which of the graphs below best shows the net force versus time for this object?



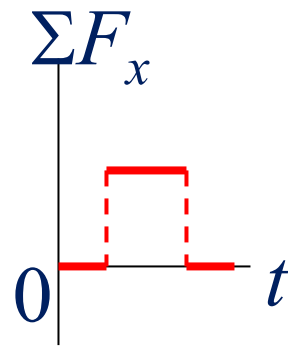
A.



B.



C.



D.



$$\vec{a} = \frac{dv}{dt}$$

$$\vec{F}_{net} = \sum \vec{F} = \vec{A} + \vec{B} + \vec{C} = m\vec{a}$$

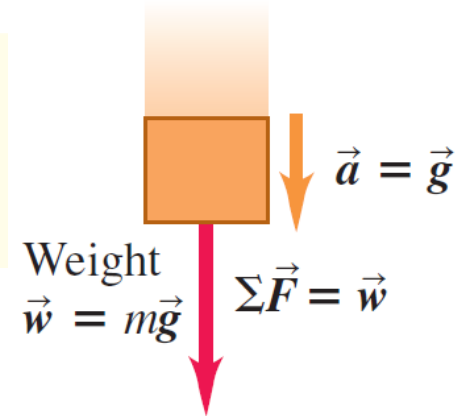
Mass and Weight

- 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:

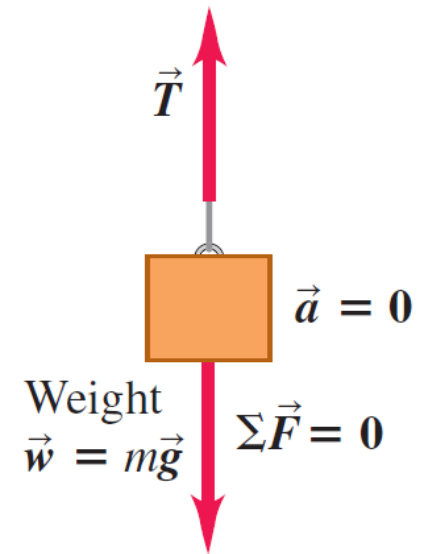
Magnitude of weight of an object $w = mg$ Mass of object
Magnitude of acceleration due to gravity

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

Falling object,
mass m



Hanging object,
mass m



- The relationship of mass to weight: $\vec{w} = m\vec{g}$.
- This relationship is the same whether an object is falling or stationary.

Example:

An elevator is being lifted at a **constant speed** by a steel cable attached to an electric motor. There is no air resistance, nor is there any friction between the elevator and the walls of the elevator shaft.

The upward force exerted on the elevator by the cable is

Q1: First law or second law? Constant speed first law.

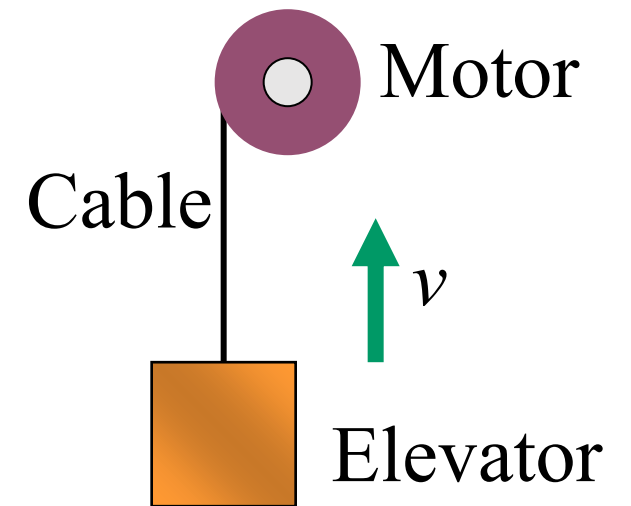
Q2: Net force? First law valid when net force is zero.

A. greater than the downward force of gravity.

B. equal to the force of gravity.

C. less than the force of gravity.

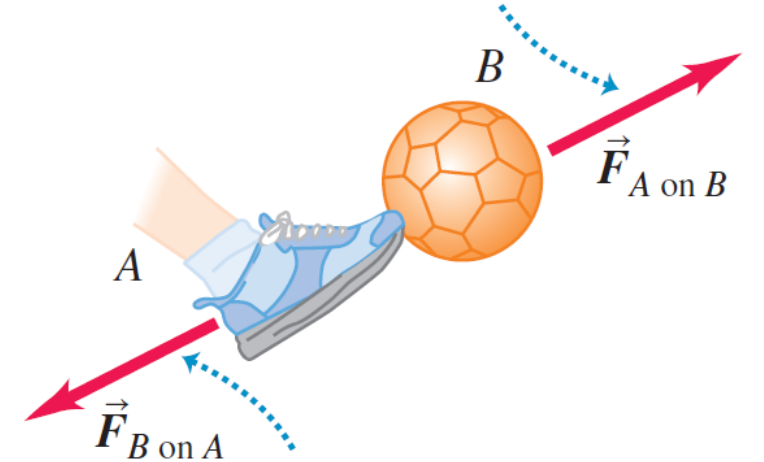
D. any of the above, depending on the speed of the elevator.



Newton's Third Law: Pair force

- If object 1 and object 2 interact, the force exerted by object 1 on object 2 is equal in magnitude but **opposite** in direction to the force exerted by object 2 on object 1.
- Two forces have the same magnitude but opposite directions: $\vec{F}_{A \text{ on } B} = -\vec{F}_{B \text{ on } A}$
- $\vec{F}_{A \text{ on } B}$ may be called the **action** force and $\vec{F}_{B \text{ on } A}$ the **reaction** force.
- The **action** and **reaction** forces act on **two different** objects.

If object A exerts force $\vec{F}_{A \text{ on } B}$ on object B (for example, a foot kicks a ball) ...



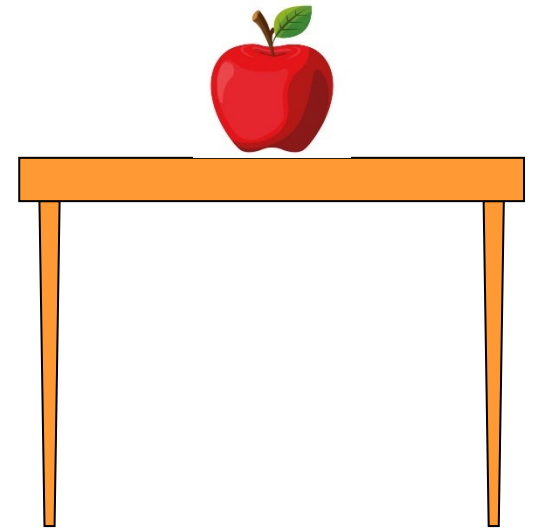
... then object B necessarily exerts force $\vec{F}_{B \text{ on } A}$ on object A (ball kicks back on foot).

Example: Basic

An apple sits at rest on a horizontal table top.

The gravitational force on the apple (its weight) is one half of an action–reaction pair. Which force is the other half?

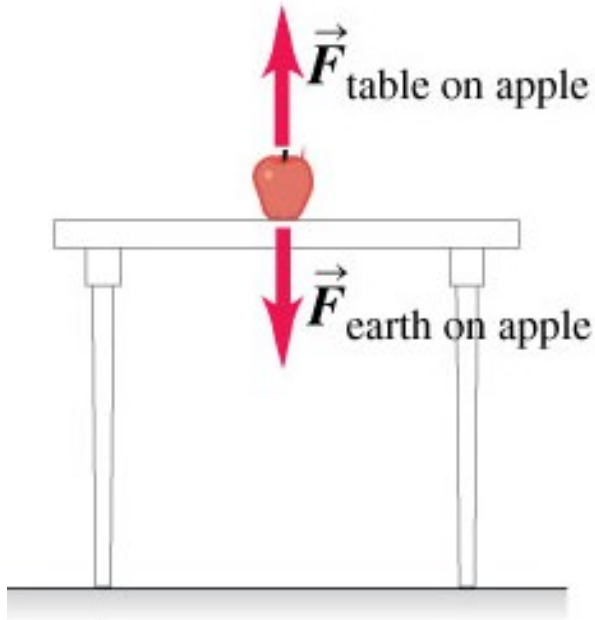
- A. the force of the earth's gravity on the apple
- B. the upward force that the table top exerts on the apple
- C. the downward force that the ball exerts on the table top
- D. the upward force that the apple exerts on earth



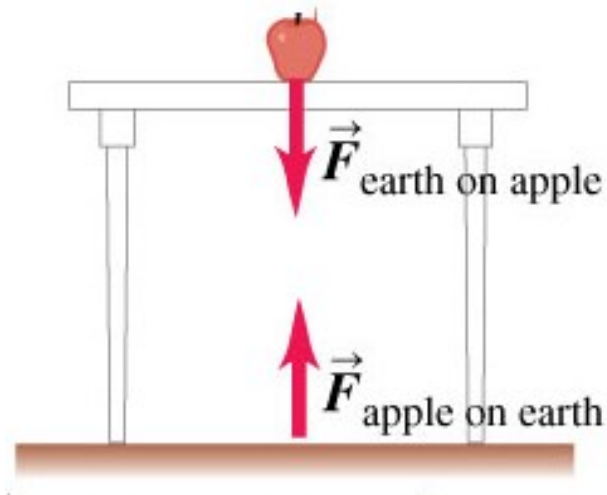
Applying Newton's Third Law: Objects at rest

- An apple rests on a table. Identify the action-reaction pairs.

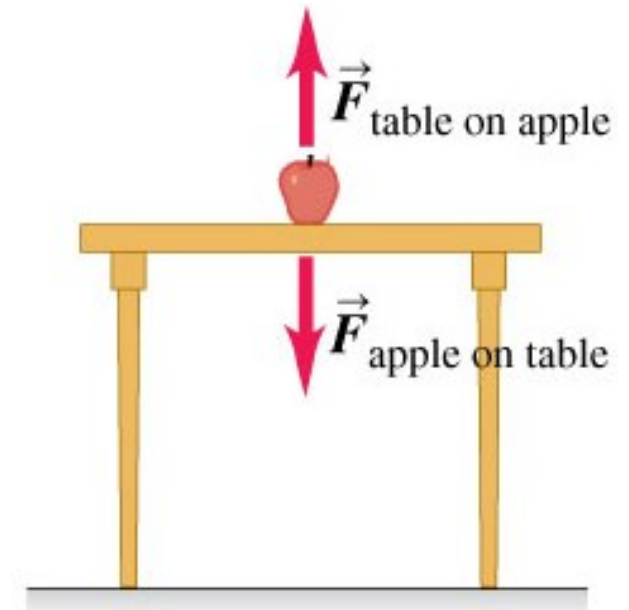
$$\vec{F}_{A \text{ on } B} = -\vec{F}_{B \text{ on } A}: \text{ on two different objects}$$



Action-reaction pairs?



$$\vec{F}_{\text{Apple on Earth}} = -\vec{F}_{\text{Earth on Apple}}$$

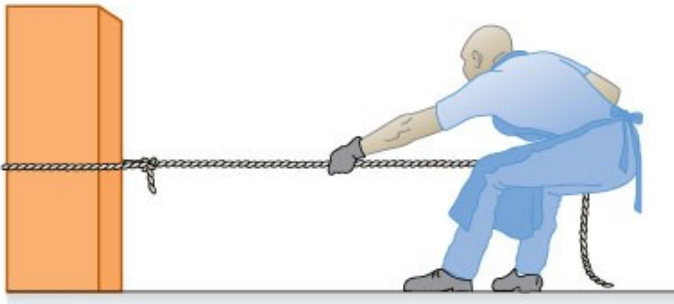


$$\vec{F}_{\text{Table on Apple}} = -\vec{F}_{\text{Apple on Table}}$$

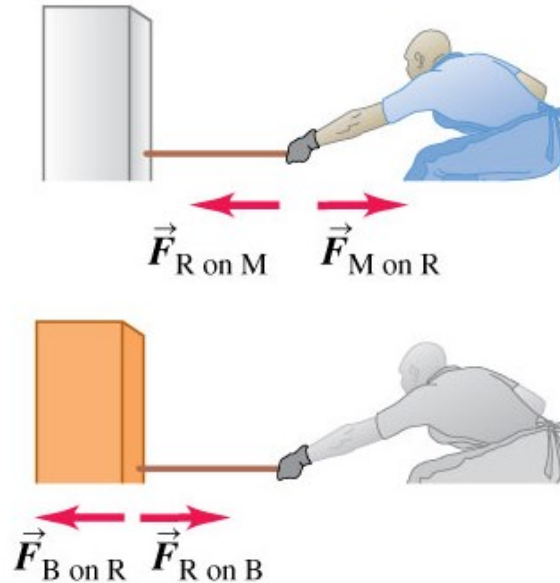
Third Law: Objects in motion

- A person pulls on a block across the floor. Identify the action-reaction pairs.

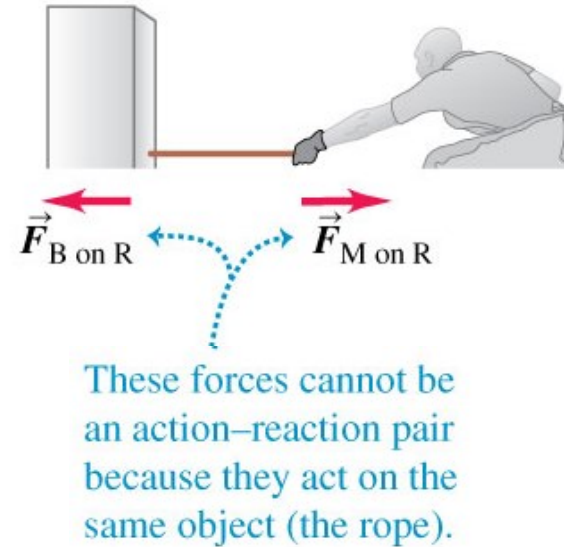
(a) The block, the rope, and the mason



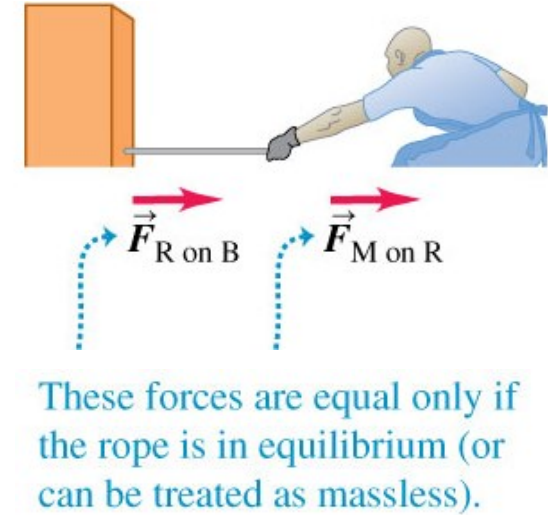
(b) The action–reaction pairs



(c) *Not* an action–reaction pair



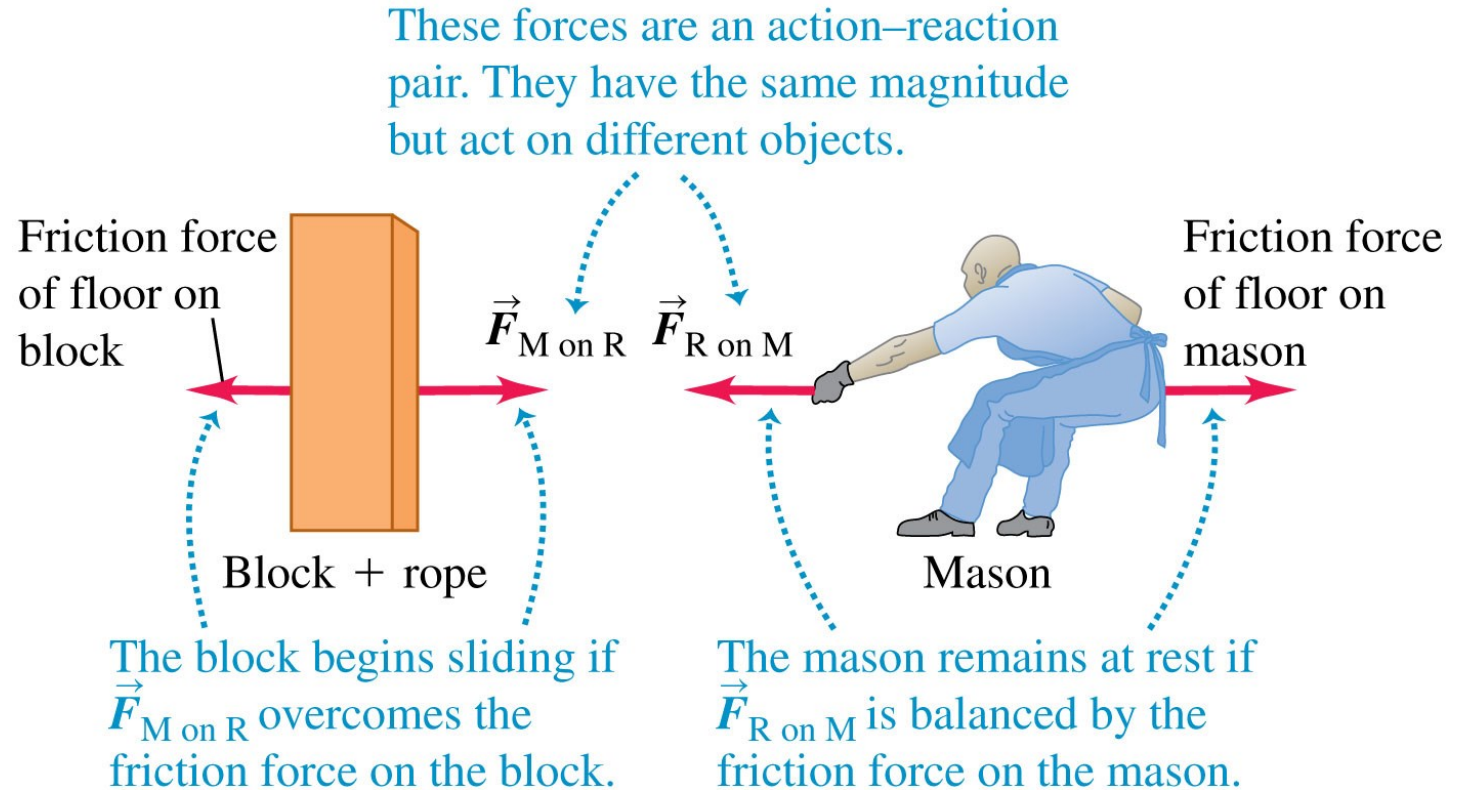
(d) Not necessarily equal



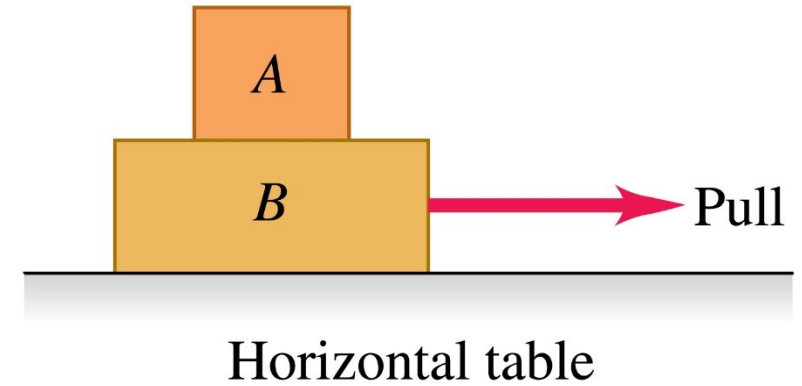
A paradox?

- If an object pulls back on you just as hard as you pull on it, how can it ever accelerate?

Friction force!



Example: A person pulls horizontally on block B , causing both blocks to move horizontally as a unit. There is friction between block B and the horizontal table. If the two blocks are moving to the right at **constant velocity**, which the following statement is correct?



- A. the horizontal force that B exerts on A points to the left.
- B. the horizontal force that B exerts on A points to the right.
- C. answer depends on the strength of the pull.
- D. B exerts no horizontal force on A .

Free-body diagrams

- The most important step in solving problems involving Newton's Laws is to draw the free body diagram.

(1) Be sure to include only the forces acting on the **object of interest**.

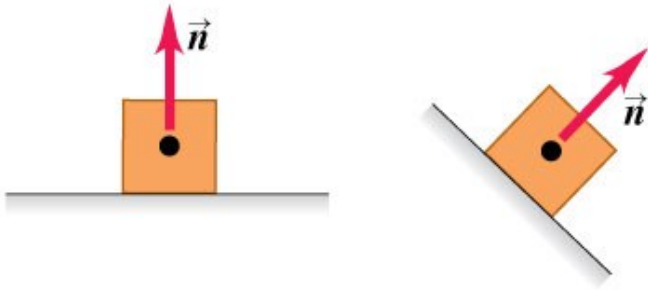
(2) Include any field forces acting on the object.

(3) Do not assume the normal force equals the weight.

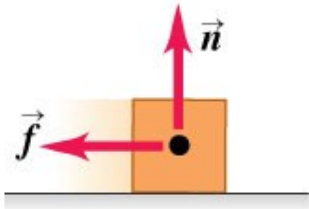


Free-body diagram: Various Forces

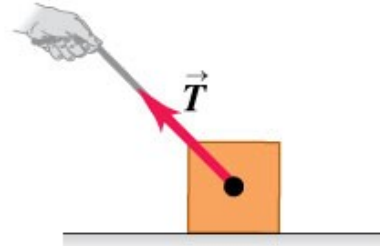
(a) **Normal force \vec{n} :** When an object rests or pushes on a surface, the surface exerts a push on it that is directed perpendicular to the surface.



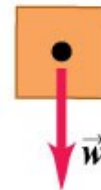
(b) **Friction force \vec{f} :** In addition to the normal force, a surface may exert a frictional force on an object, directed parallel to the surface.



(c) **Tension force \vec{T} :** A pulling force exerted on an object by a rope, cord, etc.



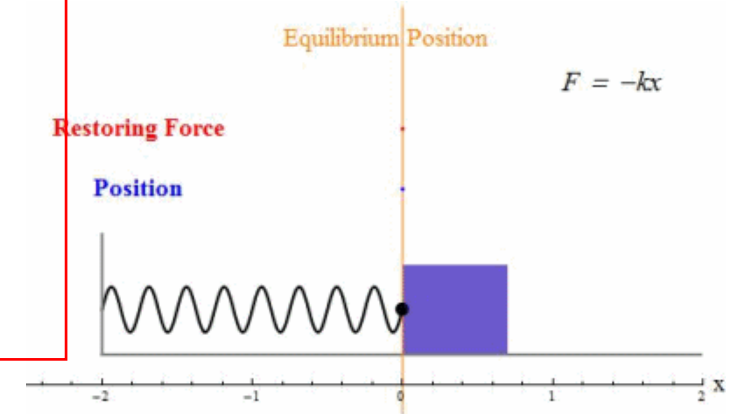
(d) **Weight \vec{w} :** The pull of gravity on an object is a long-range force (a force that acts over a distance).



Gravitational Force

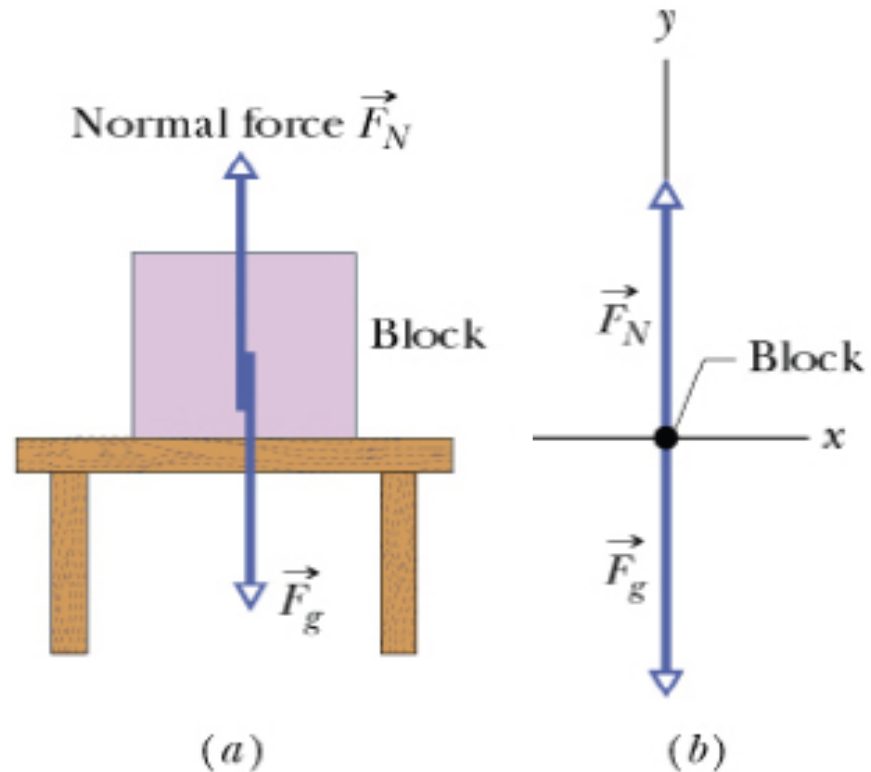
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- Spring Force



Normal Force

- Force from a solid surface which keeps object from falling through.
- **Direction: always perpendicular to the surface.**
- Magnitude: depend on situation.



$$\vec{F}_N + \vec{F}_g = m\vec{a}$$

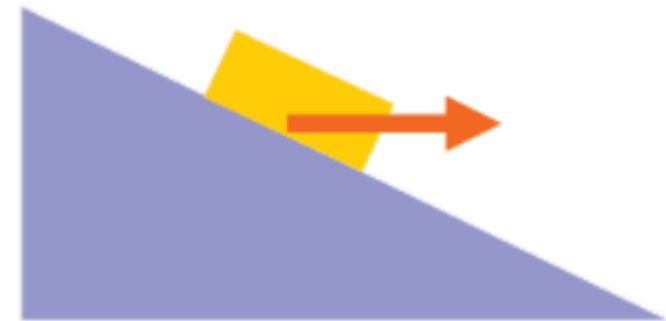
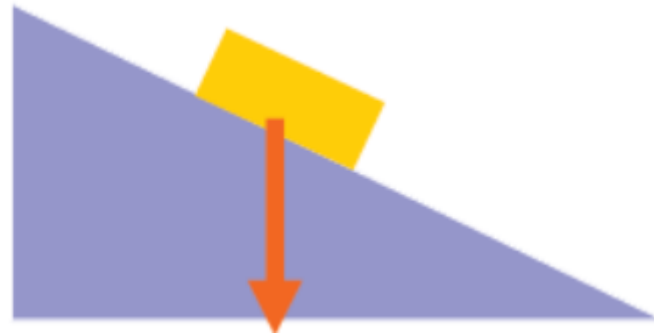
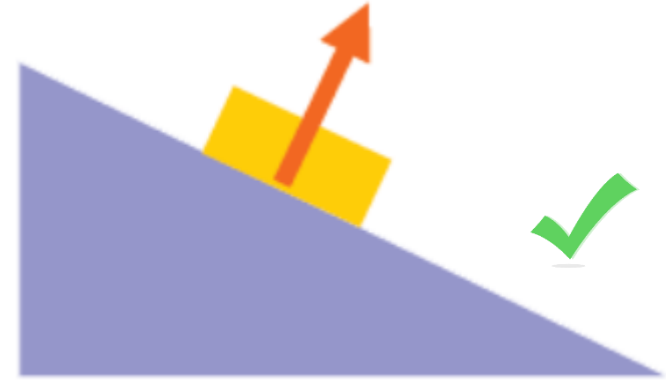
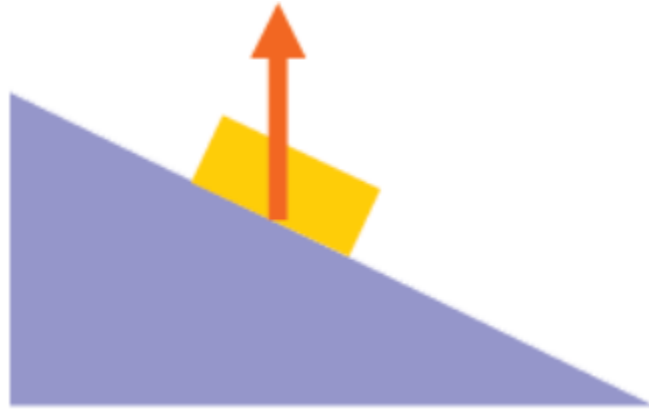
$$F_N - mg = ma_y$$

$F_N = mg$ **only** if $a_y = 0$ and no other forces are present

If a_y is not zero, F_N does not equal to $w = mg$!

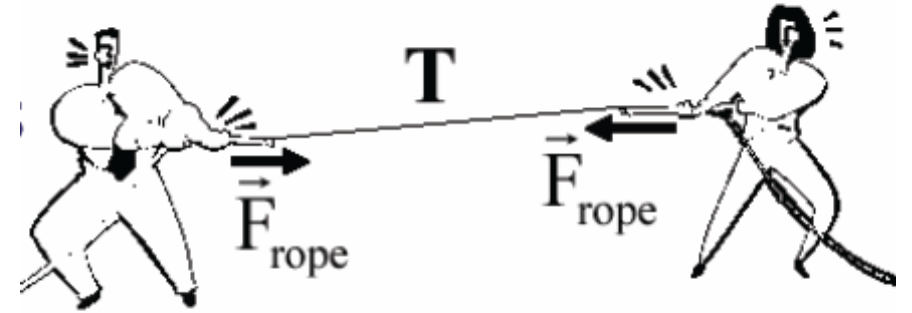
Example:

Which diagram can represent the normal force acting on the block on a ramp?

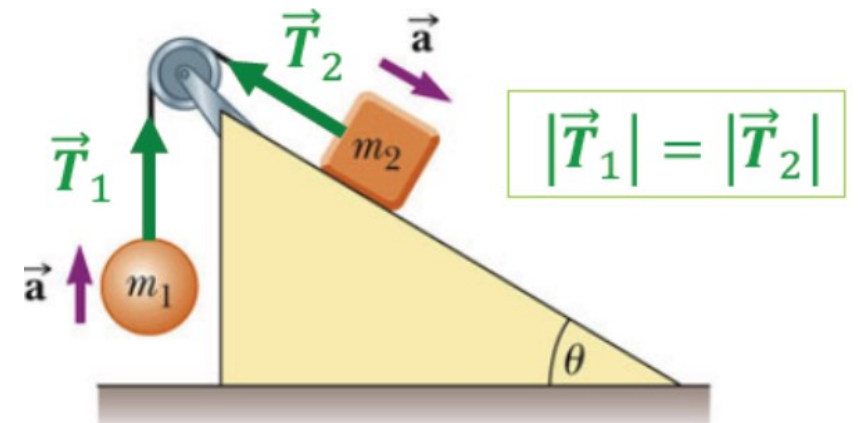


Tension Force: T

- A taut rope exerts forces on whatever holds its ends.
- **Direction: always along the cord** (rope, cable, string et al) **and away from the object.**
- Sometimes simplified as **massless** and **unstretchable** cord: $\vec{T}_1 = \vec{T}_2$, $|\vec{a}_1| = |\vec{a}_2|$
- Magnitude: depend on situation



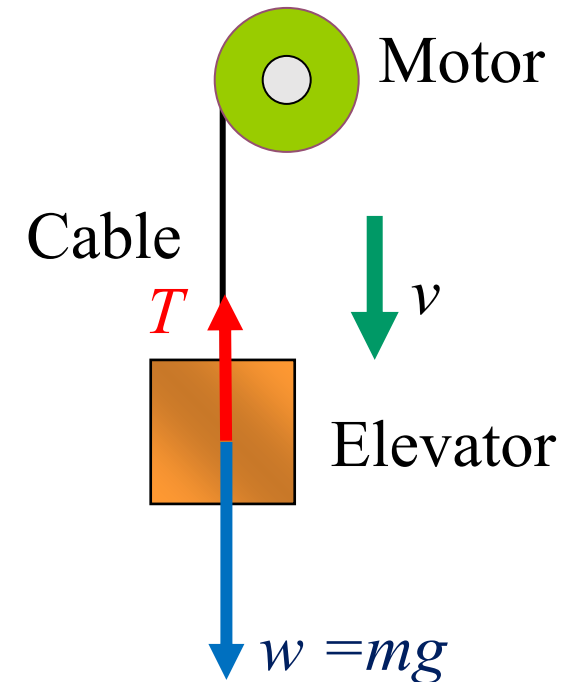
$$|\vec{F}_{\text{on A}}| = T = |\vec{F}_{\text{on B}}|$$



Example:

An elevator is being **lowered** at a **constant acceleration** by a steel cable attached to an electric motor. There is no air resistance, nor is there any friction between the elevator and the walls of the elevator shaft. The upward force exerted on the elevator by the cable is

- A. greater than the downward force of gravity.
- B. equal to the force of gravity.
- C. less than the force of gravity.
- D. any of the above, depending on the speed of the elevator.



Example: An elevator (1000 kg) is being **lowered** at an **acceleration 1 m/s²** by a steel cable attached to an electric motor. There is no air resistance, nor is there any friction between the elevator and the walls of the elevator shaft. What is the upward force exerted on the elevator by the cable?

Step 1: draw force diagram and write down equation of \vec{F}_{net} .

$$\Sigma F_y = w + T = mg - T = (1000 \text{ kg})(9.8 \text{ m/s}^2) - T$$

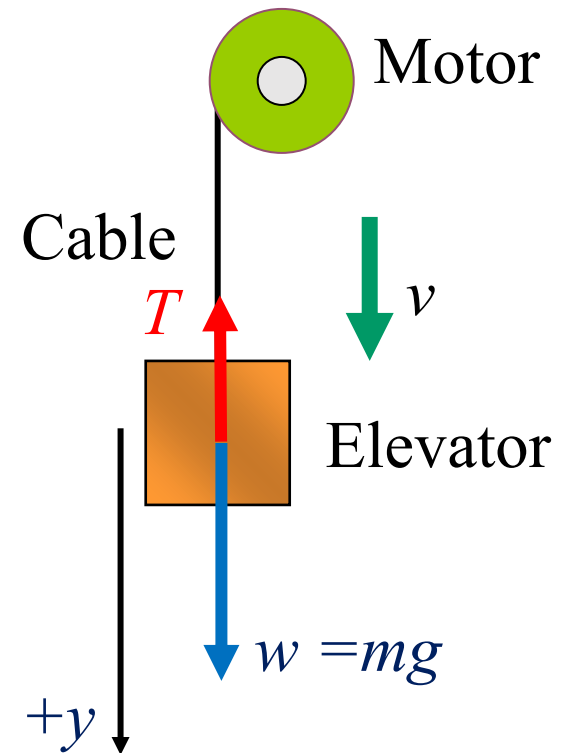
Step 2: Newton's Second Law and \vec{F}_{net} .

$$\Sigma F_y = ma_y = (1000 \text{ kg})(1 \text{ m/s}^2)$$

Step 3: Solve the problem.

$$\Sigma F_y = (1000 \text{ kg})(1 \text{ m/s}^2) = (1000 \text{ kg})(9.8 \text{ m/s}^2) - T$$

$$T = 8800 \text{ N}$$



Example:

A woman pulls on a 6.00-kg crate, which in turn is connected to a 4.00-kg crate by a light rope. The light rope remains taut. If the two crates are accelerating to the right with an acceleration $a = 2 \text{ m/s}^2$

What is the force F and tension force T ? (No friction)

Step 1: draw force diagram and write down equation of \vec{F}_{net} , for each object.

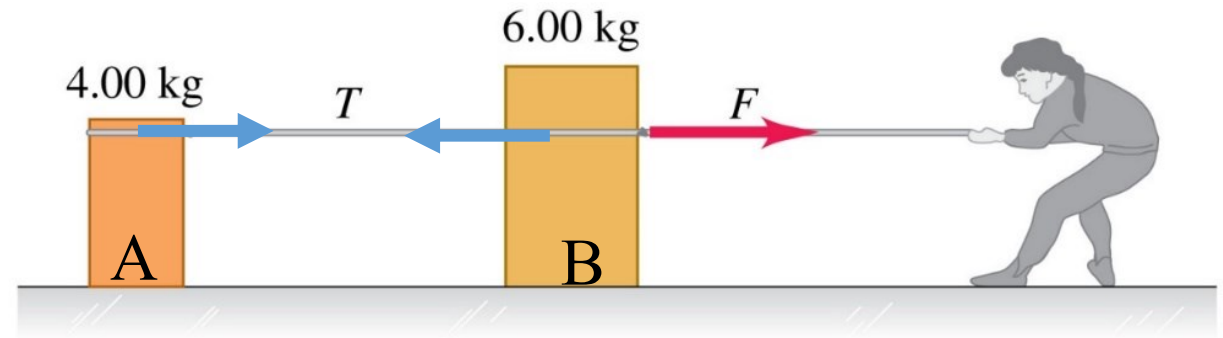
$$\sum F_{Ax} = T \qquad \sum F_{Bx} = F - T$$

Step 2: Apply Newton's Second Law.

$$\sum F_{Ax} = ma_{Ax} = (4 \text{ kg})(2 \text{ m/s}^2) = 8 \text{ N} = T$$

$$\sum F_{Bx} = ma_{Bx} = (6 \text{ kg})(2 \text{ m/s}^2) = 12 \text{ N}$$

Step 3: Solve the problem. $\sum F_{xB} = 12 \text{ N} = F - T = F - 8 \text{ N}$ $F = 12 + 8 = 20 \text{ N}$



Example: Boxes A and B are connected to each end of a light vertical rope. A constant upward force $F = 80.0$ N is applied to box A. Starting from rest, box B descends 12.0 m in 4.0 s. The tension in the rope is 36.0 N. What are the masses of box B and A?

Step 1: draw force diagram and write down equation of \vec{F}_{net} , for each object.

$$\sum F_{Ay} = T + m_A g - F$$

$$\sum F_{By} = m_B g - T$$

Step 2: Apply Newton's Second Law.

$$\sum F_{Ay} = T + m_A g - F = m_A a$$

$$\sum F_{By} = m_B g - T = m_B a$$

Q: How to find a ? $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$

$$a_y = \frac{2(y - y_0)}{t^2} = \frac{2(12.0 \text{ m})}{(4.0 \text{ s})^2} = 1.5 \text{ m/s}^2$$

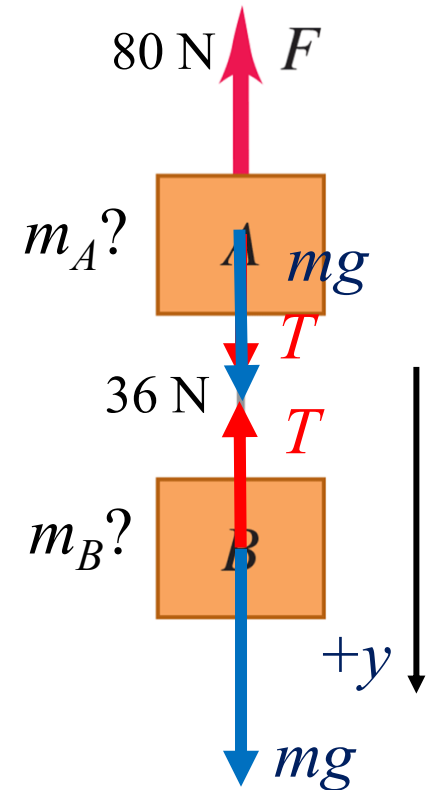
Step 3: Solve the problem

$$(36 \text{ N}) + m_A g - (80 \text{ N}) = m_A (1.5 \text{ m/s}^2)$$

$$m_A = 5.3 \text{ kg}$$

$$m_B g - (36 \text{ N}) = m_B (1.5 \text{ m/s}^2)$$

$$m_B = 4.34 \text{ kg}$$



Example:

The right figure shows two masses: $m_1 = 4.0$ kg and $m_2 = 6.0$ kg which are connected by a massless rope passing over a massless and frictionless pulley. Mass m_1 moves on a frictionless incline with $\theta = 30^\circ$. Find the magnitude of the acceleration of mass m_2 .

$$T - m_1 g \sin(30^\circ) = m_1 a \quad T = m_1 a + m_1 g \cos(30^\circ)$$

$$m_2 g - T = m_2 a$$

$$m_2 g - m_1 g \sin(30^\circ) - m_1 a = m_2 a$$

$$a = \frac{(m_2 - m_1 \sin(30^\circ))g}{m_1 + m_2} = 3.9 \text{ m/s}^2$$

