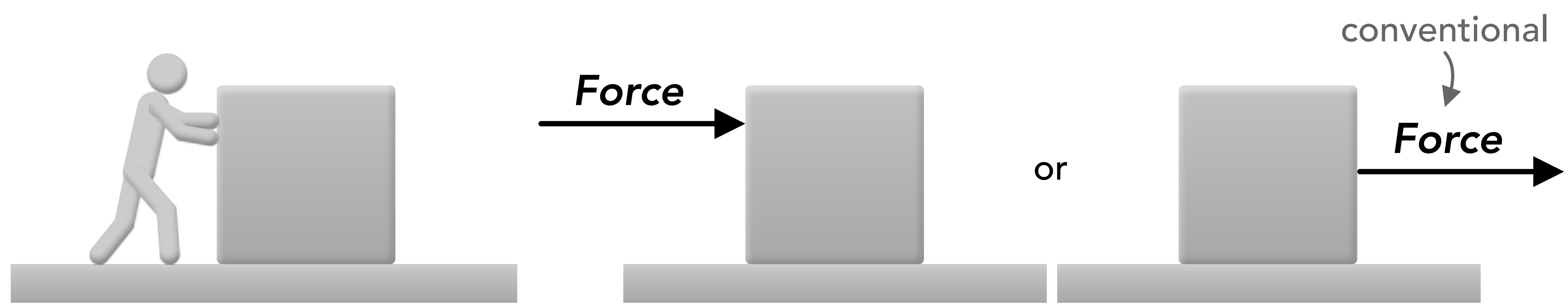
NEWTON'S 1ST & 2ND LAWS

Forces

- A **force** is a push or a pull that acts on an object and is caused by something else. For example, if you push on a box then you are applying a force on the box. The force is acting on the box and the force is caused by you.
- Multiple forces can be acting on an object at the same time.
- Forces are **vector** quantities which means they have a magnitude (a strength or value) and a direction. Forces are often described using vector arrows which have a length (representing the magnitude) and a direction. The force vector arrow typically starts on the object that the force is acting on and points in the direction of the push or pull.
- Forces are not visible, but you can often see the effect of a force, like the motion (or lack of motion) of an object.
- The forces acting on an object are related to the object's motion (or lack of motion) as described by Newton's laws of motion. However, a force exists on its own regardless of how an object is moving.
- The SI unit of force is a **Newton (N)** which is derived from other SI units: $N = kg{\cdot}m/s^2$. 1 Newton (1 N) is equal to approximately 0.22 pounds of force (lbf).

A person pushes a box to the right

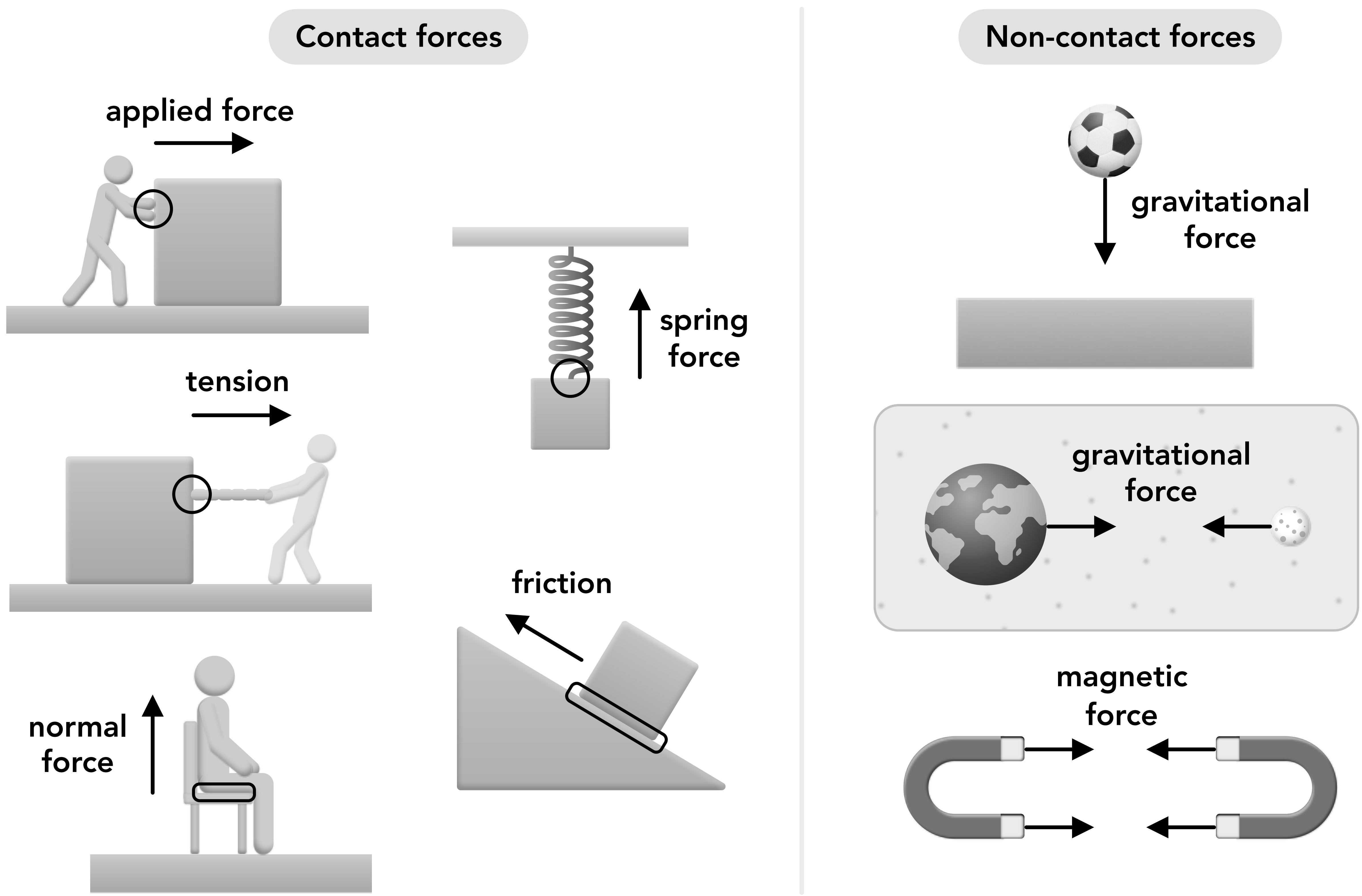
- A force is acting **on** the box
- The force is caused **by** the person
- The force vector can be drawn in different places



A person pulls a rope attached to a box to the right

- A force is acting **on** the box
- The force is caused **by** the rope

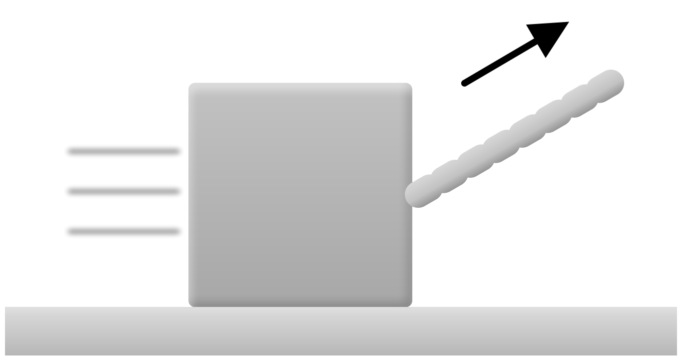
- There are different types of forces which can be grouped into 2 categories: contact forces and non-contact forces.
- **Contact forces** are when the object and the thing causing the force are in contact with each other. These forces are usually easier to "see" and they include any push or pull using contact, a friction force, a tension force, a spring force and a normal force (or reaction force).
- **Non-contact forces** are when the object and the thing causing the force are not in contact with each other. These forces are harder to "see" because the force is acting from a distance. These include the gravitational force (or weight force), magnetic force and electrostatic force.



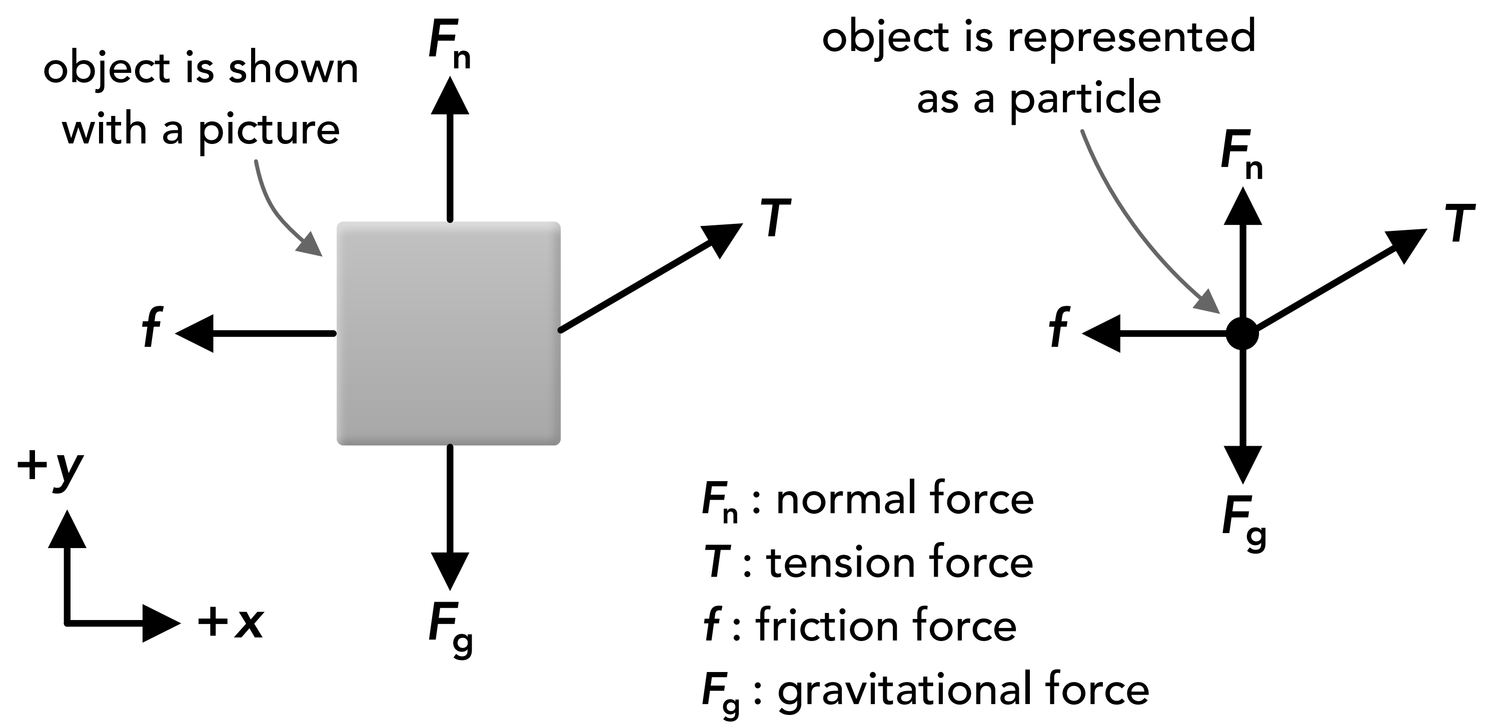
Free Body Diagrams

- A **free body diagram (FBD)** or a **force diagram** is a picture that shows a single object or system (a body) and all of the forces acting on that object. We can draw the object itself or represent the object as a **particle** using a dot.
- We need to include a coordinate system which establishes the positive ***x*** and ***y*** directions.
- We do not include the things that are causing the forces, only the forces themselves.
- We do not include any forces that are caused by this object on other things, only the forces acting on this object.
- A free body diagram is used with Newton's 2nd law of motion to analyze the net force and motion of the object.

Picture of a box on the ground being pulled by a rope



Free body diagram of the box and the forces acting on the box

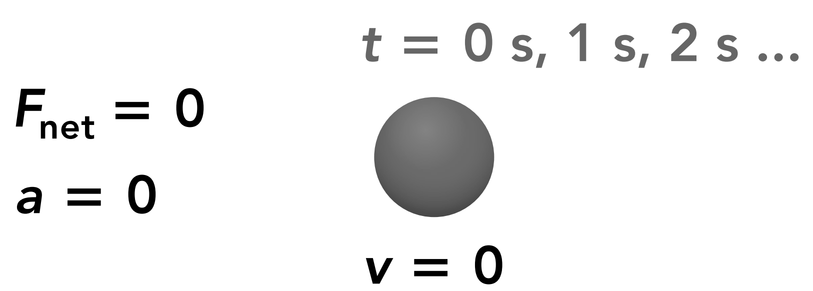


Variables		SI Unit
F	force	$N = \frac{kg \cdot m}{s^2}$
m	mass	kg
a	acceleration	$\frac{m}{s^2}$
v	velocity	$\frac{m}{s}$

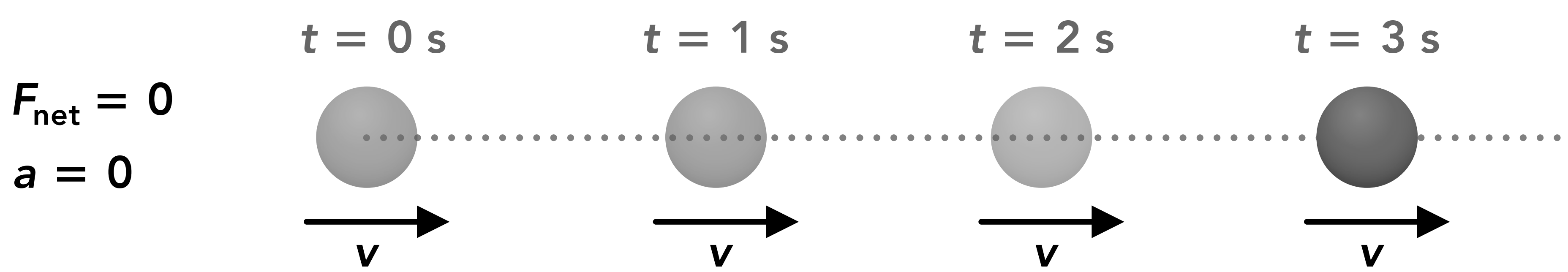
- Isaac Newton's three laws of motion describe the relationship between an object's motion and the forces that are acting on that object. These laws are the foundation for what's known as Newtonian mechanics and they describe why and how an object moves (or doesn't move), which may not be intuitive at first. They're often written in different ways, but the fundamental principle behind each law is simple and very specific as it applies to physics.

- **Newton's 1st law of motion:** An object at rest (with zero velocity) will remain at rest and an object in motion will maintain its velocity (continue moving in a straight line at a constant speed) unless there is a net force acting on the object (the vector sum of all of the forces acting on the object is not zero).
- A simpler but less descriptive version: An object will maintain its state of motion unless acted on by a net force.
- This law also provides the definition of **inertia**. Inertia is the tendency of an object to remain at rest (if at rest) or to remain in motion (if in motion), or the tendency of an object to resist a change to its current state (at rest or in motion). All objects have inertia, which is proportional to their **mass**.

An object at rest (with zero velocity) will remain at rest
if there is no net force acting on it



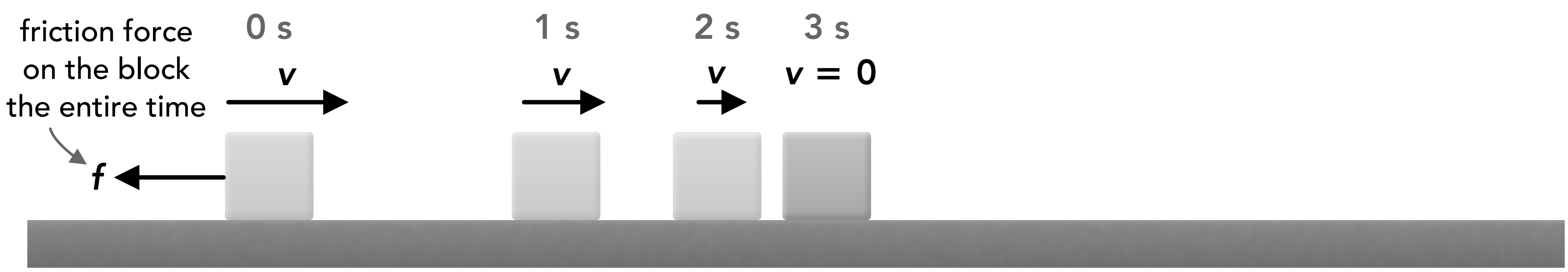
An object in motion will maintain its velocity (move in a straight line at a constant speed)
if there is no net force acting on it



- This law means that **an object which is already in motion does not require any force to continue moving**. The forces acting on an object do affect its motion (see Newton's 2nd law of motion), but nothing causes an object to **continue** moving at a constant velocity, it will do that on its own.
- This may not be intuitive because we often see moving objects appear to slow down and stop on their own, and it seems they would require a force to keep moving. In reality, most objects are experiencing a friction force from any surface they're touching and from the air. The friction force is causing the object to slow down, and if the friction was removed the object would continue moving forever with a constant velocity.
- When thinking about an object's motion, it might help to imagine the object is sliding on ice (with zero friction) or the object is floating in outer space (with zero friction or air resistance, and assuming no force of gravity). In the absence of any forces, the object will remain at rest or will continue moving with a constant velocity forever. Then we can add back the forces acting on the object to analyze its motion.

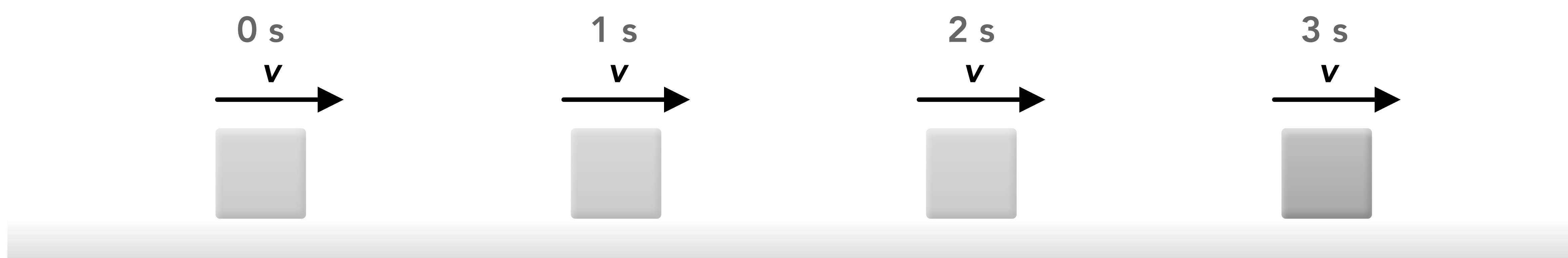
If a block is sliding on a surface with friction, the friction force causes the block to slow down and stop

$F_{net} \neq 0 \quad a \neq 0$



If a block is sliding on ice with no friction force, the block would keep moving forever

$F_{net} = 0 \quad a = 0$ (assuming no friction or air resistance)



If a block is moving freely in space with no forces acting on it, the block will keep moving forever

$F_{net} = 0 \quad a = 0$ (assuming no air resistance or other forces)

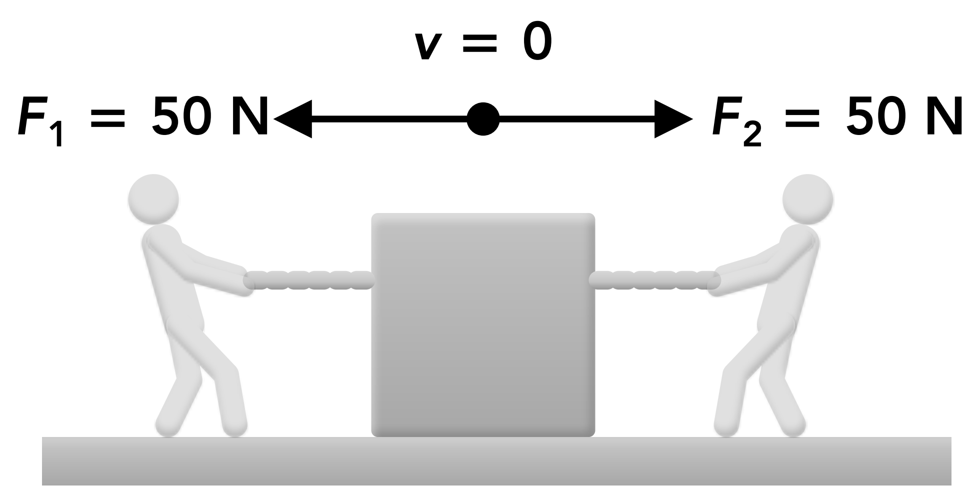
- This law also means that **an object at rest may have forces acting on it**, and **an object that is moving at a constant velocity may have forces acting on it**.
- Newton's 1st law of motion says that an object will remain at rest or maintain a constant velocity if there is no **net force** or no **unbalanced force** acting on it. If there are multiple forces acting on the object but they "cancel out" (the vector sum of all of the forces is zero) then there is no net force.
- For example, imagine an object is being pulled to the left and to the right, like in a game of tug-of-war. If the two forces are equal in magnitude (or strength) then they "cancel" each other out because they act in opposite directions. The net force on the object would be zero and the object would remain at rest (if it was already at rest), or the object would continue moving at a constant velocity (if it was already moving).

Two people pull on a box with equal force in opposite directions
- The net force acting on the box is zero (there is no unbalanced force)
- If the box is at rest, it will remain at rest and won't move

$F_1 = F_2$

$F_{net} = 0 = F_2 - F_1$

$a = 0$

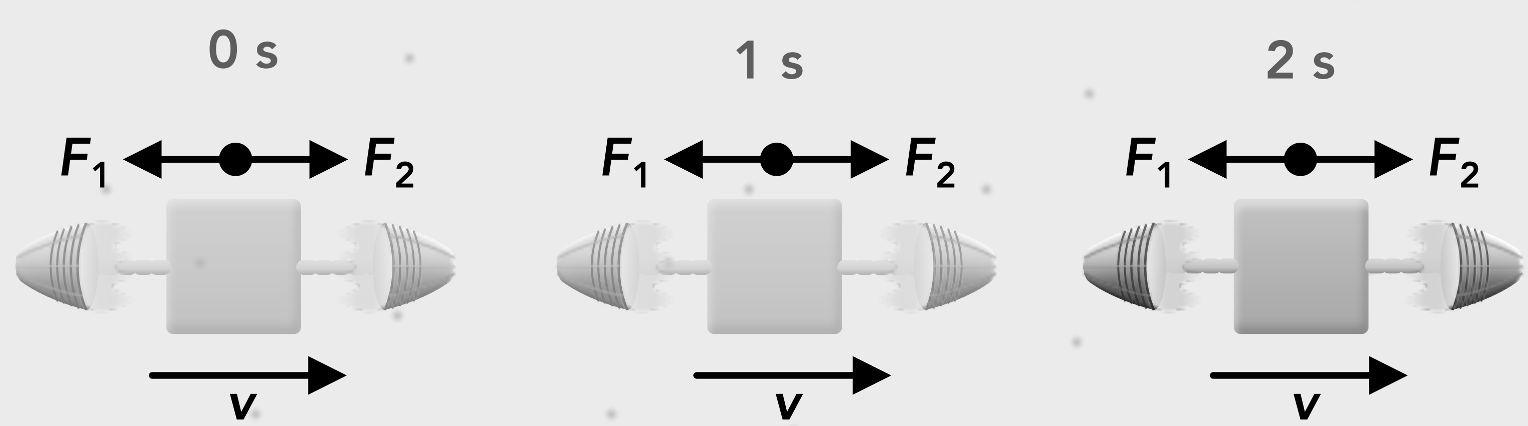


Two rocket thrusters pull on a box with equal force in opposite directions
- The net force acting on the box is zero (there is no unbalanced force)
- If the box was moving it will continue moving at a constant velocity

$F_1 = F_2$

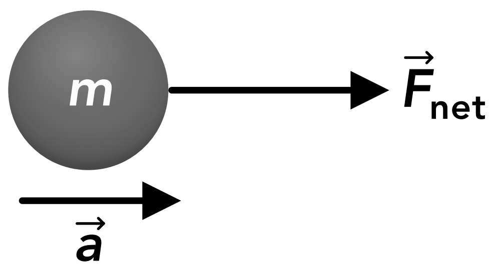
$F_{net} = 0 = F_2 - F_1$

$a = 0$



Newton's 2nd Law of Motion

- **Newton's 2nd law of motion:** A net force F_{net} (the vector sum of all forces) acting on an object of mass m will cause it to accelerate at a rate of a in the same direction as the net force, and the net force is equal to the mass multiplied by the acceleration: $F_{net} = ma$
- It's important to remember that the forces acting on an object are related to its **acceleration**, not its velocity.
- In a way, Newton's 2nd law also covers Newton's 1st law. Acceleration is the change in an object's velocity. If the net force acting on an object is zero, the acceleration is zero and the velocity will remain the same. If the object is at rest (has zero velocity) it will remain at rest. If the object is moving (has a velocity) it will maintain that velocity.
- The relationship $F = ma$ is the source of the base SI units used in the unit of force, the Newton (N).



Newton's 2nd law of motion

$$\vec{F}_{net} = m\vec{a} \quad \text{or} \quad \sum \vec{F} = m\vec{a}$$

$\sum$: the sum of __

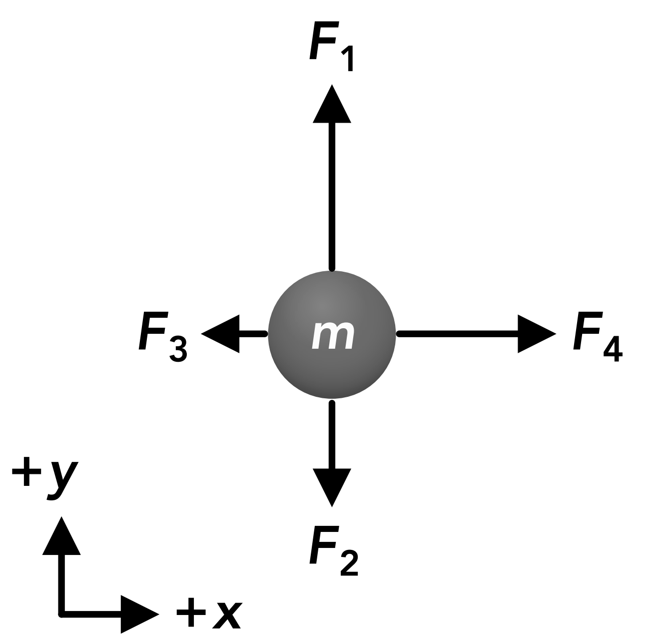
Units:

$$N = kg\,\frac{m}{s^2}$$

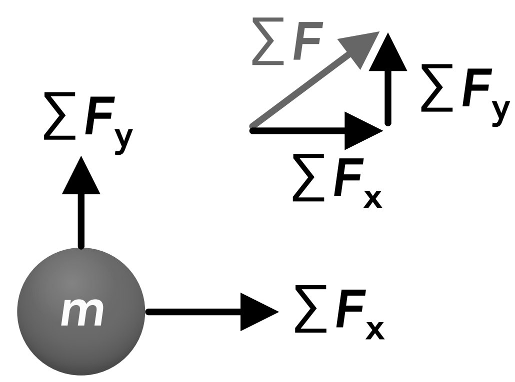
- This may be the first time we're discussing ***mass***. All objects have mass, and there are several ways to define or think about mass:
- As a simple starting point, you can think of an object's mass as the "weight" of the object. Heavier objects have more mass and lighter objects have less mass. It's important to know that mass and weight are two separate things, which will be covered later, but in the presence of gravity an object's weight is proportional to its mass.
- Mass is the amount of matter contained in an object.
- Mass is related to the inertia of an object (for now it's fair to say they are the same thing). An object with more mass has more inertia and will resist a change to its current state (at rest or in motion) more than an object with less mass. This is essentially Newton's 2nd law: the amount an object changes its motion (the acceleration) due to a net force is proportional to its mass ($F_{net} = ma$, $m = F_{net}/a$, $a = F_{net}/m$).
- The SI unit of mass is the **kilogram (kg)**.

- An important part of Newton's 1st and 2nd laws is that only a **net force** causes an acceleration, and the forces and the acceleration are **vectors**.
- Free body diagrams are used in combination with Newton's 2nd law to determine the net force vector acting on an object and the acceleration vector.
- In almost every scenario we're going to **analyze the components of the net force and the acceleration in the *x* and *y* directions separately**, just like in kinematics, because the *x* and *y* directions are independent.
- If a force is not parallel to the *x* or *y* axis then we need to find the *x* and *y* components of that force.
- We will end up with two equations (one for each direction) that describe the relationship between the forces and the acceleration. Then we can plug in all of the known values to solve for an unknown value.

Free body diagram of the forces acting on an object

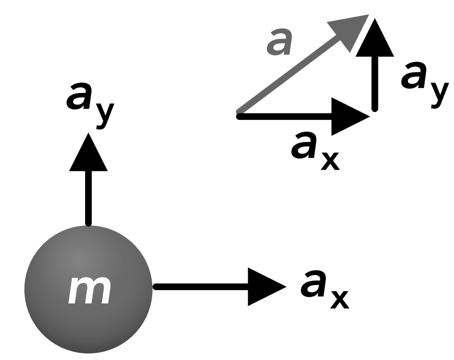


The net force acting on an object is the vector sum of all the forces

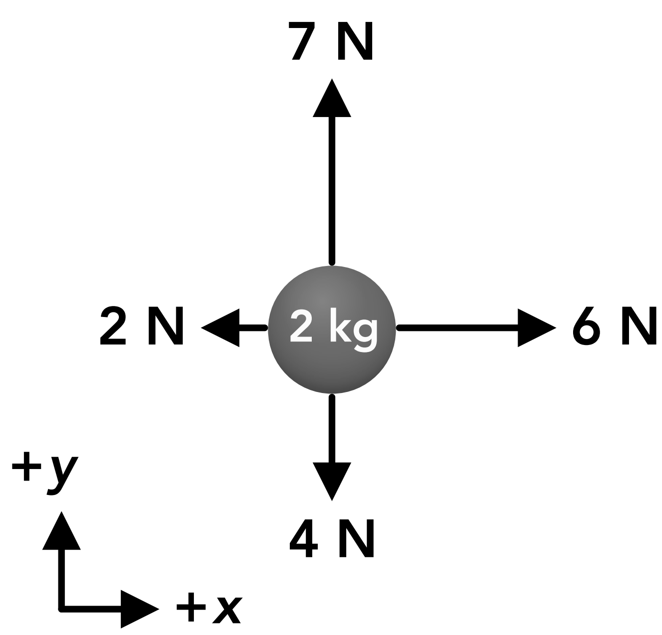


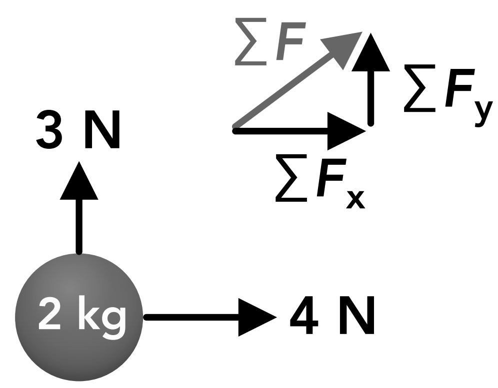
$$\sum F_x = (F_4) + (-F_3)$$
$$\sum F_y = (F_1) + (-F_2)$$

Newton's 2nd law applies to each direction

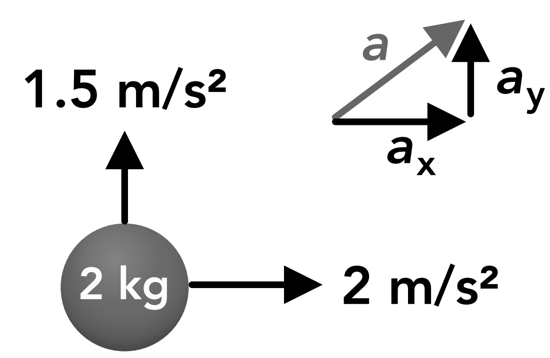


$$\sum F_x = m a_x$$
$$\sum F_y = m a_y$$





$$\sum F_x = (6\ \text{N}) + (-2\ \text{N}) = 4\ \text{N}$$
$$\sum F_y = (7\ \text{N}) + (-4\ \text{N}) = 3\ \text{N}$$

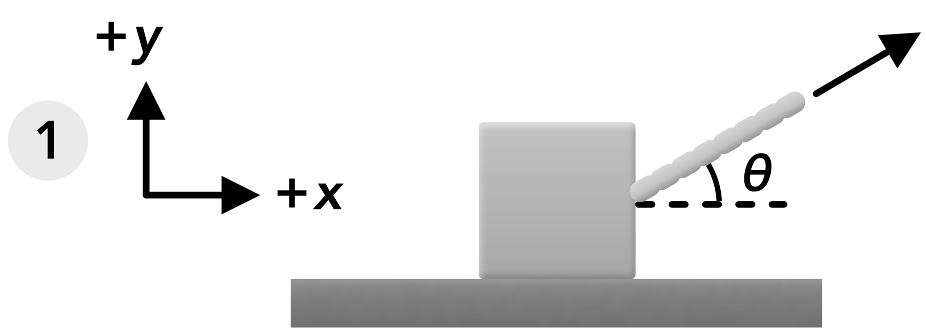


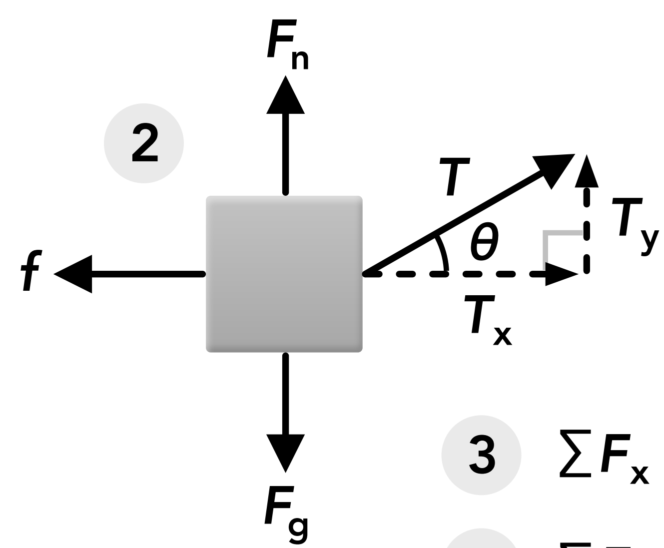
$4\ \text{N} = (2\ \text{kg})a_x \quad a_x = 2\ \text{m/s}^2$

$3\ \text{N} = (2\ \text{kg})a_y \quad a_y = 1.5\ \text{m/s}^2$

Steps for drawing a free body diagram and applying Newton's 2nd law:

1. Establish the origin and the positive directions of the ***x*** and ***y*** axes. This will determine whether each force is positive or negative when added together. It's useful to set up one of the axes parallel to the direction of the object's motion, or to have the axes parallel to most of the force vectors.
2. Draw a free body diagram of the object and all of the forces acting on the object. If a force is not parallel to one of the axes, find the ***x*** and ***y*** components of the force.
3. Add the forces in the ***x*** direction and apply Newton's 2nd law in the ***x*** direction: $\sum F_x = ma_x$
4. Add the forces in the ***y*** direction and apply Newton's 2nd law in the ***y*** direction: $\sum F_y = ma_y$
5. Use those equations to solve for an unknown variable or answer a question.





$T_y = T\sin(\theta)$

$T_x = T\cos(\theta)$

3 $\sum F_x = T_x - f = ma_x$

4 $\sum F_y = F_n + T_y - F_g = ma_y$