Flipping Physics Lecture Notes:
Introduction to Inertia and Inertial Mass

Inertia: The tendency of an object to resist a change in state of motion. A "change in state of motion" means a change in an object's velocity. $\vec{a}=\dfrac{\Delta\vec{v}}{\Delta t}$, therefore inertia can also be define as: The tendency of an object to resist acceleration.

Inertial Mass: A measure of an object's inertia. In other words, inertial mass is a measure of the tendency of an object to resist acceleration. The more mass something has, the more it resists acceleration.

(There is also gravitational mass, which, as far as we can tell experimentally, is identical to inertial mass. I will define gravitational mass at a later date. Because the two are experimentally identical, unless there is specific reason to distinguish between the two, I will refer to both inertial and gravitational mass as "mass".)

Flipping Physics Lecture Notes:
Introduction to Force

Force: Sometimes defined as a push or a pull on an object. I prefer this definition: A force is the ability to cause a change in state of motion of an object. Therefore a force is what has the ability to cause an acceleration and mass is the measurement of how much an object resists that acceleration. Because force is *the ability* to cause a change in state of motion of an object, it doesn't have to cause acceleration.

It is very important to understand that a force is *always* caused by the interaction of two objects:

Example. (Force: two objects)
The dog pulls on the leash. (Tension Force: dog & leash)
The hammer hits the nail. (Force Applied: hammer & nail)
I fall out of a tree toward the Earth (Force of Gravity: me & the Earth)
The car slides to a stop. (The Force of Friction: tires and ground)

Two types of forces are contact and field forces.

Contact forces are the result of two objects touching one another. Examples of contact forces are applied forces, drag force, friction force, force normal, spring force and tension.

Field forces are sometimes called action-at-a-distance forces because they happen even when two interacting objects are *not touching* one another, that's right, there is no physical contact between the two objects. Actually, it would be more accurate to say that they don't have to touch one another. Examples of Field forces are gravitational force, magnetic force and electric force. The gravitational force you are most familiar with, your weight, is an interaction between your body and planet Earth.

Flipping Physics Lecture Notes:
Introduction to the Force of Gravity and Gravitational Mass

The Force of Gravity, Fg is also called Weight, W. The Force of Gravity is the attractive force between exerted on an object by the Earth. The equation for the Force of Gravity is $F_g = mg$.

m in this equation refers to the *gravitational mass* of the object. Gravitational mass is defined as the mass one uses when determining the Force of Gravity acting on an object. Recall that inertial mass is the tendency of an object to resist and change in state of motion. Even though they have very different definitions, gravitational mass and inertial mass are experimentally identical.

The accepted value for the acceleration due to gravity on Earth is: $g_{Earth} = +9.81\frac{m}{s^2}$

All forces are vectors; therefore the Force of Gravity is also a vector and is *down*.

The dimensions for force can be determined using the Force of Gravity equation:

$$F_g = mg \Rightarrow (kg)\left(\frac{m}{s^2}\right) = Newton, N$$ (in SI units)

$$F_g = mg \Rightarrow (slug)\left(\frac{ft}{s^2}\right) = Pound, lb$$ (in English units)

Flipping Physics Lecture Notes:
Weight and Mass are Not the Same

Weight	*Mass*
In Newtons $\left(N = \frac{kg \cdot m}{s^2}\right)$	In Kilograms
A Vector (has both magnitude and direction)	A Scalar (has magnitude only, no direction)
An Extrinsic Property	An Intrinsic Property

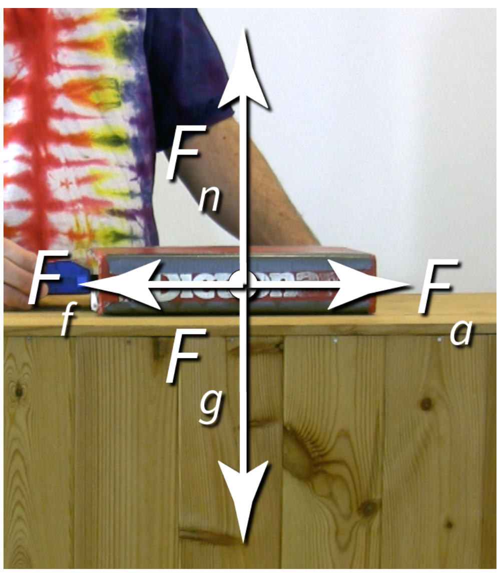
Weight is an extrinsic property, which means it depends on something external to itself.

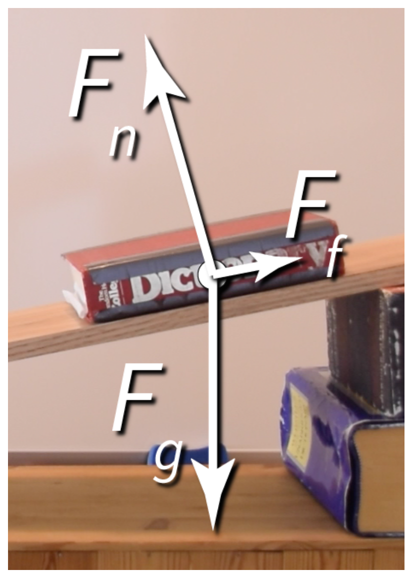
$Weight = F_g = mg$ so weight depends on the acceleration due to gravity which will change depending on the objects location.

Flipping Physics Lecture Notes:
Introduction to Free Body Diagrams or Force Diagrams

Free Body Diagram (FBD) or Force Diagram is a diagram that shows all the forces acting on an object or a "body" that is singled out from or "freed" from a group of objects.

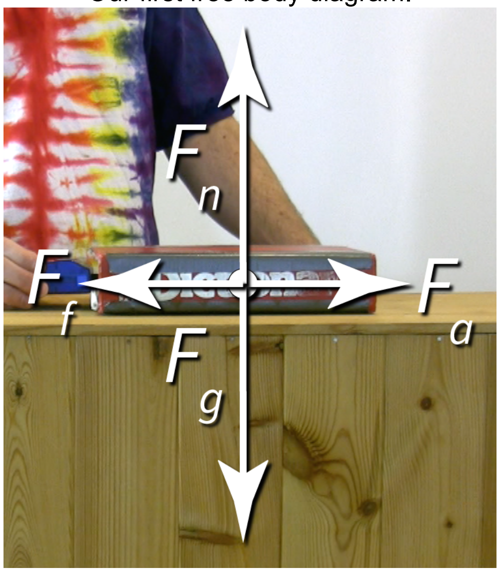
- Center of Mass: The location at which we consider all the mass of an object to be concentrated.
    - We will more precisely define center of mass in a later lesson.
- Force Normal, F_n
    - The force normal to or perpendicular to and caused by a surface.
    - Always a push. (Surfaces can't pull.)
- Force Applied, Fa
    - The force applied on an object by a different object or person.
- Force of Friction, Ff
    - Parallel to and caused by a surface.
    - Tries to prevent and object from moving or slows down an object.
    - We will define the Force of Friction in greater detail in later lessons.
- Forces are vectors and the arrow lengths in the Free Body Diagrams correspond to the magnitude of those force vectors.
    - In other words, if the Force Applied is 20 N and the Force of Friction is 10 N, then the length of the force applied vector arrow should be twice the length of the force of friction vector arrow.



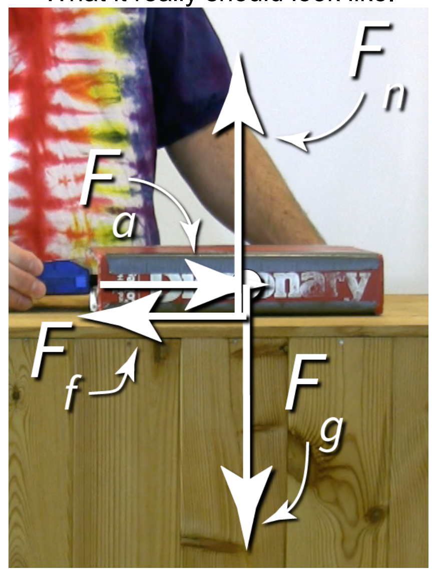


Flipping Physics Lecture Notes:
The Reality of our First Free Body Diagram

Our first free body diagram.



What it really should look like.



The reality is that the only force we can truly consider to act on the book at the books center of mass is the force of gravity[♥]. Because the force normal, force applied and force of friction are all contact forces, they all should be drawn on the book at their points of contact.

- The force applied acts on the book where the force sensor is in contact with the book.
- The force of friction and force normal act on the book where the book is in contact with the surface of the table.
- Also, we draw the Force Normal just a little bit to the left so it doesn't block the force of gravity.

Until we get to torque, we won't worry about all of this, we will just draw our Free Body Diagrams like the one on the left. ☺

[♥] Don't get me started on the fact that the force of gravity actually acts on the center of gravity. And the fact that the center of mass and the center of gravity are in the same location when the gravitational field is constant like it almost is on the surface of planet Earth. We are not there, yet.

Flipping Physics Lecture Notes:
Introduction to Newton's First Law of Motion

Sir Issac Newton's (1642 – 1726) First Law of Motion:

> **An object at rest will remain at rest and an object in motion will remain at a constant velocity unless acted upon by a net external force.**

Case #1: An object at rest will remain at rest unless acted upon by a net external force. Therefore and object that remains at rest will have a net external force of zero acting on it. This does not mean there are no forces acting on it; it simply means that when you add up all the forces you get a value of zero.

Case #2: An object in motion will maintain a constant velocity unless acted upon by a net external force. This means, because velocity is a vector, that an object in motion will maintain a constant speed and direction unless acted upon by a net external force. Again, this does not mean there are no forces acting on the object, it means the sum of the external forces is zero.

Newton's 1st Law of Motion is often called the Law of Inertia. Inertia is the tendency of an object to resist a change in state of motion. So Newton's first law is about how an object maintains its state of motion.

The two most common mistakes students make are underlined here: An object at rest will remain at rest and an object in motion will remain at a <u>constant velocity</u> unless acted upon by a <u>net external</u> force. Students will often say that on object in motion will remain in motion, which is not correct. And students will often leave of the "net external".

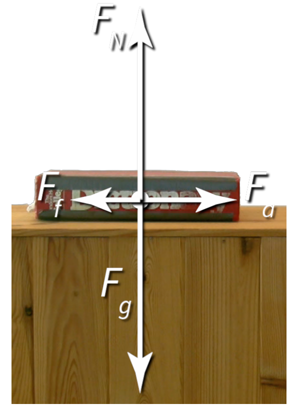
Flipping Physics Lecture Notes:
Introduction to Newton's Second Law of Motion with Example Problem

Newton's Second Law of Motion: $\sum \vec{F} = m\vec{a}$

The Net force equals mass times acceleration where force and acceleration are both vectors.

Example problem: You apply a force of 5.0 N horizontally to a 1627 g book that is at rest on a horizontal table. If the force of friction between the book and table is 3.6 N:

a) What are the magnitudes of all the forces acting on the book?
b) What is the acceleration of the book?



Givens: $\boxed{F_a = 5.0\text{ N},\ F_f = 3.6\text{ N},}$ $m = 1627\text{ g}$, $v_i = 0$

Draw the Free Body Diagram.

We have an equation for the Force of Gravity or Weight of the book. However, we need to convert the mass of the book before we use it to kg because Newtons is in $\frac{kg \cdot m}{s^2}$.

$$m = 1627g \times \frac{1kg}{1000g} = 1.627kg \text{ \&}$$

$$F_g = mg = (1.627)(9.81) = 15.961 \approx \boxed{16N}$$

Sum the forces in the y-direction:

$$\sum F_y = F_n - F_g = ma_y = m(0) = 0 \Rightarrow F_n - F_g = 0 \Rightarrow F_n = F_g = 15.961 \approx \boxed{16N}$$

Force Normal and Force of Gravity have the same magnitude and are in opposite directions.
That completes part (a) because we already knew the magnitudes of the Force Applied and Force of Friction.

Sum the forces in the x-direction:

$$\sum F_x = F_a - F_f = ma_x \Rightarrow a_x = \frac{F_a - F_f}{m} = \frac{5 - 3.6}{1.627} = 0.86048 \approx \boxed{0.86\frac{m}{s^2}}$$

This is how you show the dimensions work out to be meters per second squared:

$$a_x = \frac{F_a - F_f}{m} \Rightarrow \frac{N}{kg} = \frac{\frac{kg \cdot m}{s^2}}{kg} = \frac{\frac{kg \cdot m}{s^2}}{\frac{kg}{1}} = \frac{kg \cdot m}{s^2} \times \frac{1}{kg} = \frac{m}{s^2}$$

You can see that we can use Newton's Second Law of Motion to determine the acceleration of a mass caused by a net external force. Because those forces are constant, the acceleration is also constant and we could use the Uniformly Accelerated Motion (UAM) equations to find out more information about the book.

The 4 UAM Equations: $\Delta x = v_i \Delta t + \frac{1}{2} a \Delta t^2;\ v_f = v_i + a\Delta t;\ v_f^2 = v_i^2 + 2a\Delta x;\ \Delta x = \frac{1}{2}(v_f + v_i)\Delta t$

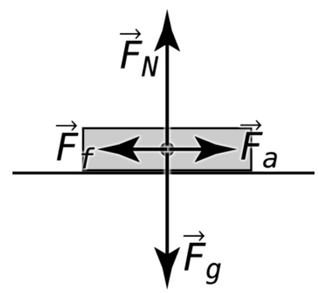
Flipping Physics Lecture Notes:
A "Show All Your Work!" Example
http://www.flippingphysics.com/show-work-example.html

A while back we had a lesson where I described why I require that you “Show All Your Work!”[1]. Today let’s look at an example of something students typically want to skip, however, I require that you write down every time. A basic example of a book at rest on a level surface with a person applying a force to the right on the book.

One major step in many solutions involving this situation will include using Newton’s Second Law in the y-direction like this:

$$\sum F_y = F_N - F_g = ma_y = m(0) = 0 \Rightarrow F_N - F_g = 0 \Rightarrow F_N = F_g$$

Early on in introductory physics, in many situations, force normal and force of gravity are equal in magnitude: $F_N = F_g$. Because of this many of you will assume the magnitude of the force normal and the force of gravity are *always* equal. THIS IS NOT TRUE.

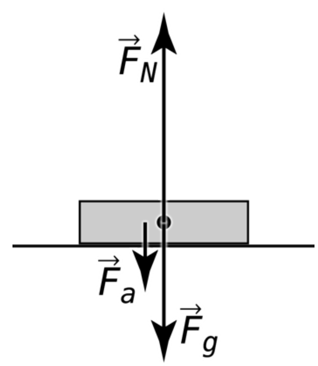


If you get into the habit of always thinking your way through and writing out the equations, you will understand when force normal and force of gravity are not equal in magnitude. There are many, many situations where this happens, however, it takes a bit of time in introductory physics to get to those situations. Some examples:

- An object in an accelerating elevator.[2]
- An object on an incline.[3]
- An object being held against a vertical wall.[4]
- When a car goes over a hill.[5]
- A painter on a scaffold.[6]

In fact, a simple example of where the force normal and the force of gravity are not equal in magnitude is if I push straight down on the book.

$$\sum F_y = F_N - F_g - F_a = ma_y = m(0) = 0$$
$$\Rightarrow F_N - F_g - F_a = 0 \Rightarrow F_N = F_g + F_a$$



[1] Why "Show All Your Work"?: http://www.flippingphysics.com/show-work.html
[2] “Do You Feel Your Weight? A lesson on Apparent Weight”: https://www.flippingphysics.com/apparent-weight.html
[3] “Introductory Static Friction on an Incline Problem”: https://www.flippingphysics.com/static-friction-incline.html
[4] “Dynamics Review for AP Physics 1”: https://www.flippingphysics.com/ap1-dynamics-review.html
[5] “Introductory Centripetal Force Problem - Car over a Hill”: https://www.flippingphysics.com/centripetal-force-problem.html
[6] “Painter on a Scaffold - Don't Fall Off!”: https://www.flippingphysics.com/painter-scaffold.html

Flipping Physics Lecture Notes:
Introductory Newton's 2nd Law Example Problem and Demonstration
(or Finding the Force of Friction between a Dynamics Cart and Track)

Newton's Second Law of Motion: $\sum \vec{F} = m\vec{a}$

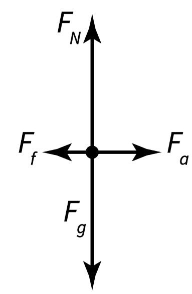
Example Problem: A 613 g cart is released from rest on a horizontal track and travels 52.0 cm in 1.15 seconds while experiencing an average, horizontal applied force of 0.490 N. What is the magnitude of the force of friction between the cart and the track?

Known Values: $m = 613g;\ v_i = 0;\ \Delta x = 52.0cm;\ \Delta t = 1.15s;\ F_a = 0.490N;\ F_f = ?$

Convert mass to kg: $m = 613g \times \frac{1kg}{1000g} = 0.613kg$

Convert displacement to meters: $\Delta x = 52.0cm \times \frac{1m}{100cm} = 0.52m$

Draw the Free Body Diagram of the forces acting on the cart:



Use Newton's Second Law:

$$\sum F_x = F_a - F_f = ma_x \Rightarrow F_a = ma_x + F_f \Rightarrow F_f = F_a - ma_x$$

The only variable we don't know is the acceleration in the x-direction. We can consider the acceleration to be constant because the forces are constant (or at least very close to constant). Therefore we can use the uniformly accelerated motion equations:

$$\Delta x = v_{ix}\Delta t + \frac{1}{2}a_x\Delta t^2 = (0)\Delta t + \frac{1}{2}a_x\Delta t^2 = \frac{1}{2}a_x\Delta t^2 \Rightarrow a_x\Delta t^2 = 2\Delta x \Rightarrow a_x = \frac{2\Delta x}{\Delta t^2}$$

$$\Rightarrow a_x = \frac{(2)(0.52)}{1.15^2} = 0.786389\frac{m}{s^2}$$

And now we can go back to the equation for friction and substitute in numbers:

$$F_f = F_a - ma_x = (0.49) - (0.613)(0.786389) = 0.00794329 \approx \boxed{0.00794N}$$

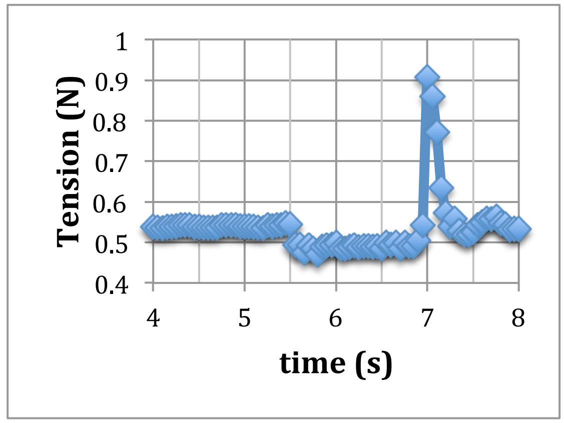
Is the force of friction negligible?

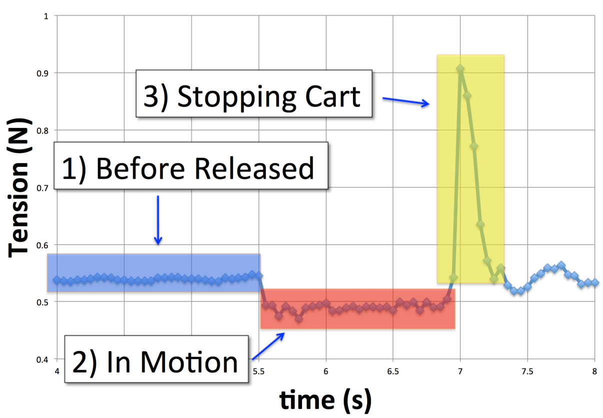
$$\frac{F_f}{F_a} = \frac{0.00794329}{0.490} = 0.0162108 \approx 0.016 \Rightarrow 0.016 \times 100 = 1.6\%$$

Flipping Physics Lecture Notes:
Force vs. Time on a Dynamics Cart

This is an extension of a previous lesson:
Introductory Newton's 2nd Law Example Problem and Demonstration.
www.flippingphysics.com/second-law-problem.html

A yellow string is attached to a 0.613 kg cart and a 0.0550 kg mass. The cart is placed on a horizontal track and the string is placed over a pulley. The tension as a function of time before and after the cart is released is show in the graph to the right.





There are three main parts of the motion we are going to analyze.

1) Before the cart is released.
2) While the cart is in motion.
3) While the cart is being stopped.

We start by drawing the free body diagrams. Notice there are two free body diagrams because there are two objects in motion, the cart and the mass hanging. So both the cart and the mass hanging have a free body diagram.

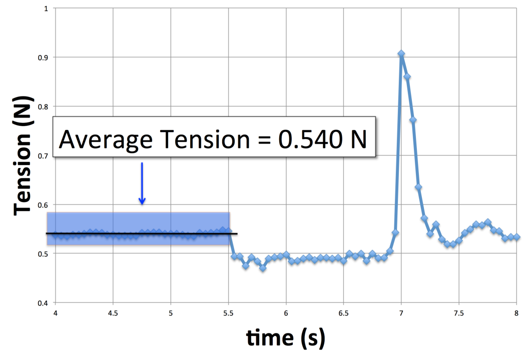
Note: Because it is the same string and the pulley has negligible mass and friction, the force of tension at either end of the string is the same. In other words, the force of tension in both free body diagrams has the same value. Which means the tension force in our graph applies to both free body diagrams. Before we analyze the situation by using Newton's Second Law of Motion: $\sum \vec{F} = m\vec{a}$, we need to identify a direction. The cart will accelerate to the right and the mass hanging will accelerate downward, however, they will have the same acceleration because they are attached by the string. Therefore we call the cart and mass hanging, the System. Let's identify the positive direction as the direction the cart and mass hanging move. (Which I already identified in the picture.) Let's call this the String Direction.

Let's sum the forces *on the mass hanging, in the direction of the string, during part* ***one***, before I release the cart:

$$\sum F = F_{g_h} - F_T = m_h a \Rightarrow F_{g_h} = F_T + m_h a \Rightarrow F_T = F_{g_h} - m_h a = m_h g - m_h a = m_h\left(g - a\right)$$

$$F_T = \left(0.055\right)\left(9.81 - 0\right) = 0.53955 \approx 0.540N$$

This is a theoretical prediction of the Tension force in the string and it matches our experimental values.



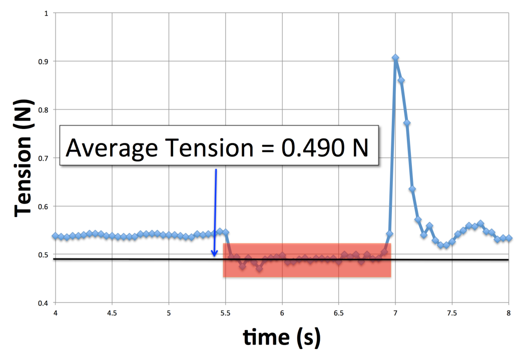
Let's sum the forces *on the mass hanging, in the direction of the string, during part* ***two***, after I release the cart, while the cart is accelerating. In the previous lesson we determined the acceleration of the cart and mass hanging: $a = 0.786389\frac{m}{s^2}$

$$\sum F = F_{g_h} - F_T = m_h a \Rightarrow F_{g_h} = F_T + m_h a \Rightarrow F_T = F_{g_h} - m_h a = m_h g - m_h a = m_h\left(g - a\right)$$

$$\Rightarrow F_T = \left(0.055\right)\left(9.81 - 0.786389\right) = 0.496299 \approx 0.496N$$

Notice this is close to the experimental value, however, not quite the same.

Also notice that the tension force in the string changes, even though the free body diagram of the forces acting on the mass hanging does not change. Why? Because the acceleration of the mass hanging changes.

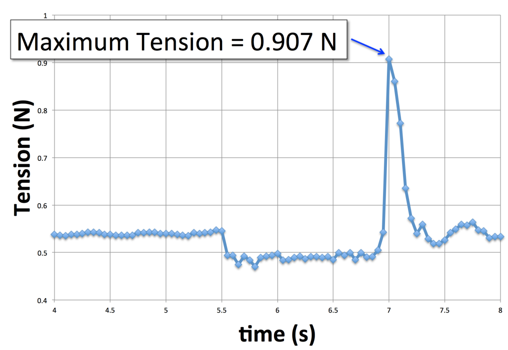


Now let's sum the forces *on the mass hanging, in the direction of the string, during part* ***three***, while I am stopping the cart. Notice the force is not close to constant, so let's sum the forces at the point when there is the maximum tension in the string.

$$\sum F = F_{g_h} - F_T = m_h a \Rightarrow a = \frac{F_{g_h} - F_T}{m_h} = \frac{m_h g - F_T}{m_h} = \frac{\left(0.055\right)\left(9.81\right) - 0.907}{0.055}$$

$$\Rightarrow a = -6.680909 \approx -6.68\frac{m}{s^2}$$

This is the maximum acceleration of the cart. Notice it is an instantaneous value and not an average value like we determined in the first two parts.

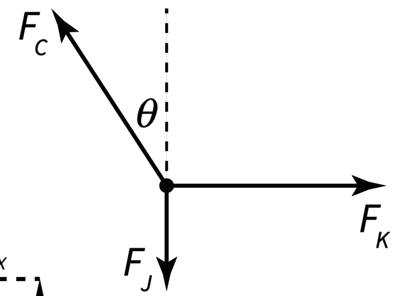


Flipping Physics Lecture Notes:
A Three Force Example of Newton's 2nd Law with Components
(or 3 Brothers Fighting over a Stuffed Turtle)

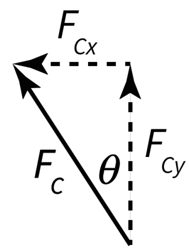
Example Problem: Three brothers Ken, Jim and Chris all want Ken's stuffed turtle. Each is pulling with a horizontal force. If Ken pulls Eastward with 270 N, Jim pulls Southward with 130 N and Chris pulls with 260 N at an angle of 33° W of N, what is the net force caused by the three brothers on the stuffed turtle?

Known Values: $\vec{F}_K = 270N\ E;\ \vec{F}_J = 130N\ S;\ \vec{F}_C = 260N\ @\ 33^\circ W\ of\ N;\ \sum \vec{F} = ?$

Draw the Free Body Diagram:



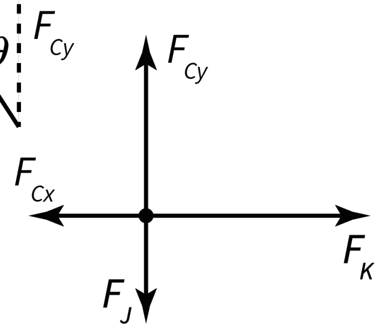
Before we can sum the forces we need to break all the forces that are not directly in the x or y direction in to their components. The only force we need to break in to components is $\vec{F}_C$.



$$\cos\theta = \frac{A}{H} = \frac{F_{Cy}}{F_C} \Rightarrow F_{Cy} = F_C \cos\theta = 260\cos(33) = 218.054N$$

$$\sin\theta = \frac{O}{H} = \frac{F_{Cx}}{F_C} \Rightarrow F_{Cx} = F_C \sin\theta = 260\sin(33) = 141.606N$$

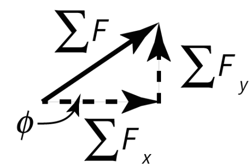
Redraw the Free Body Diagram.
Sum the forces in the x and y directions.



$$\sum F_x = -F_{Cx} + F_K = -141.606 + 270 = 128.394N$$

$$\sum F_y = -F_J + F_{Cy} = -130 + 218.054 = 88.054N$$

Use the Pythagorean theorem to solve for the magnitude of the net force.



$$a^2 + b^2 = c^2 \Rightarrow \left(\sum F_x\right)^2 + \left(\sum F_y\right)^2 = \left(\sum F\right)^2 \Rightarrow \sum F = \sqrt{\left(\sum F_x\right)^2 + \left(\sum F_y\right)^2}$$

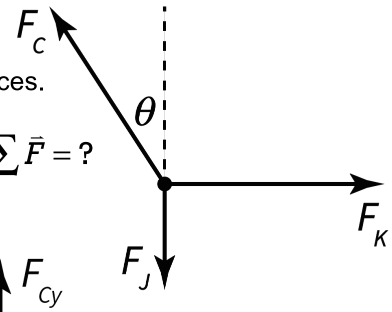
$$\Rightarrow \sum F = \sqrt{128.394^2 + 88.054^2} = 155.687 \approx 160N$$

Now we need the direction.

$$\tan\phi = \frac{O}{A} = \frac{\sum F_y}{\sum F_x} \Rightarrow \phi = \tan^{-1}\left(\frac{\sum F_y}{\sum F_x}\right) = \tan^{-1}\left(\frac{88.054}{128.394}\right) = 34.4429 \approx 34^\circ$$

$$\boxed{\sum \vec{F} \approx 160N @ 34^\circ N\ of\ E}$$

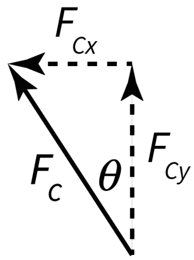
Flipping Physics Lecture Notes:
Summing the Forces is Vector Addition



We just completed a problem where we found the net force caused by three forces.

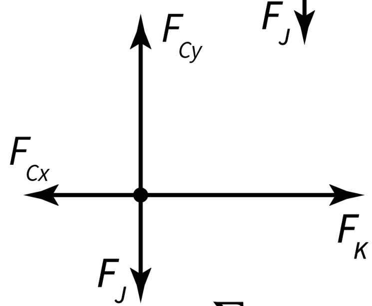
Known Values: $\vec{F}_K = 270N\ E;\ \vec{F}_J = 130N\ S;\ \vec{F}_C = 260N\ @\ 33^\circ W\ of\ N;\ \sum \vec{F} = ?$
(K = Ken, J = Jim, C = Chris)

We drew the free body diagram.

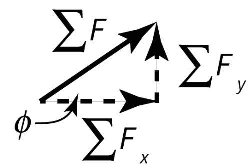


Broke the force of Chris in to its components.
$F_{Cy} = 218.054N\ \&\ F_{Cx} = 141.606N$

Redrew the Free Body Diagram:



Determined the net force in the x & y directions:
$\sum F_x = 128.394N\ \&\ \sum F_y = 88.054N$



Used the Pythagorean theorem to solve for the magnitude of the net force.
$\sum F = 155.687 \approx 160N$

Used tangent to find the direction.

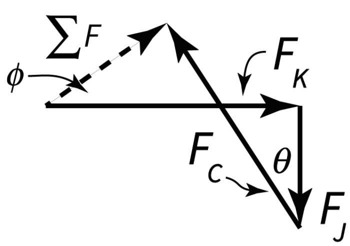
$$\phi = \tan^{-1}\left(\frac{88.054}{128.394}\right) = 34.4429 \approx 34^\circ$$

And found the net force.

$$\boxed{\sum \vec{F} \approx 160N @ 34^\circ N\ of\ E}$$

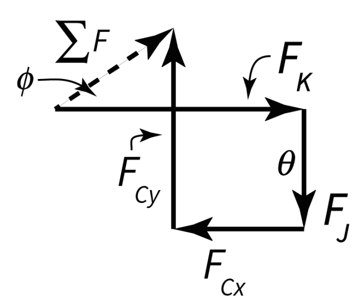
(Clearly the above is just a summary. Please see the previous video for a complete solution. http://www.flippingphysics.com/three-force-example.html)

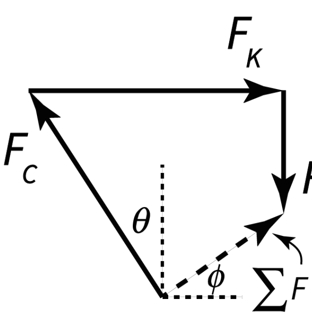
Even though it doesn't quite look like it, summing the forces is vector addition. So let's do the problem visually as tip-to-tail vector addition:



$\sum \vec{F} = \vec{F}_K + \vec{F}_J + \vec{F}_C$ (left diagram)

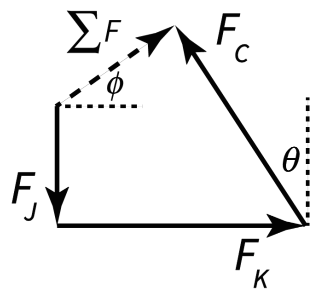
Or you can include the components of the force of Chris instead.
$\sum \vec{F} = \vec{F}_K + \vec{F}_J + \vec{F}_{Cx} + \vec{F}_{Cy}$ (right diagram)





Remember the order of the vectors is irrelevant so we could add the vectors in different orders.

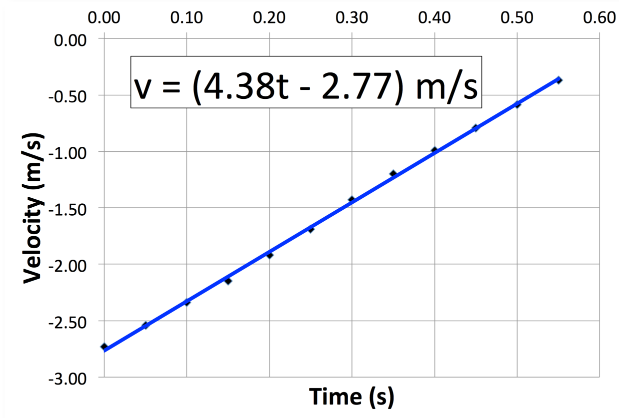
$\sum \vec{F} = \vec{F}_C + \vec{F}_K + \vec{F}_J$ (left diagram)
or $\sum \vec{F} = \vec{F}_J + \vec{F}_K + \vec{F}_C$ (right diagram)
and we always get the same net force as before.



We could even solve this problem using a data table like we did when we introduced vector addition: (http://www.flippingphysics.com/data-table.html)

Vector:	x-direction (N)	y-direction (N)
$\vec{F}_K$	270	0
$\vec{F}_C$	-141.606	218.054
$\vec{F}_J$	0	-130
$\sum F$	$\sum F_x = 270 - 141.606 + 0 = 128.394N$	$\sum F_y = 0 + 218.054 - 130 = 88.054N$

So, it may not look like it at first, but summing the forces is simply another way to do vector addition.



We haven't defined the Force of Friction♥ yet, however, we can still solve for its magnitude.

Example Problem: You slide a 56 gram street hockey puck on a wooden board. The graph of its velocity as a function of time is shown. What is the magnitude of the force of friction between the puck and the wooden board?

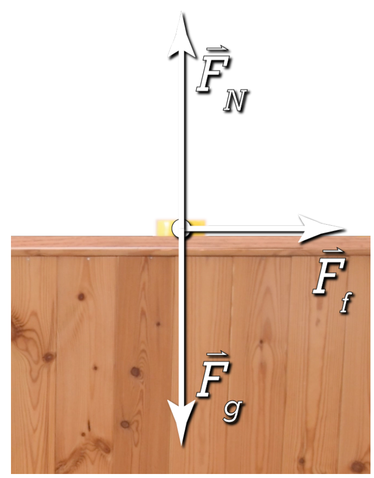
The best-fit line or trendline of the velocity as a function of time graph is $v = \left(4.38t - 2.77\right)\frac{m}{s}$

This line equation is in the slope intercept form or y = mx +b, which means the slope of the line or m = 4.38 and the y-intercept or b = -2.77. Remember the slope of a velocity versus time graph is acceleration:

$$slope = m = \frac{rise}{run} = \frac{\Delta y}{\Delta x} = \frac{\Delta v}{\Delta t} = a = 4.38\frac{m}{s^2}$$

The y-intercept is the initial velocity: $v_i = -2.77\frac{m}{s}$

Draw the free body diagram to solve for the force of friction.



Sum the forces in the x-direction:

$$\sum F_x = F_f = ma_x = \left(56\right)\left(4.38\right) = 245.28N \times \frac{1lb}{4.448N} = 55.144lb$$

Something must be wrong because the force of friction acting on an object with such a small mass shouldn't be that large! We didn't convert the puck mass to kg, which we need to do because Newtons are in $\frac{kg \cdot m}{s^2}$.

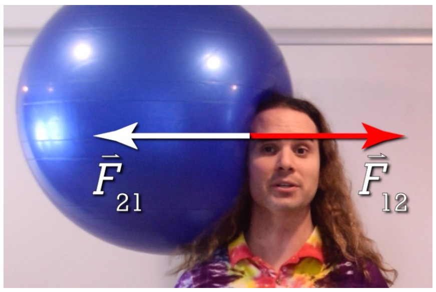
$$m = 56g \times \frac{1kg}{1000g} = 0.056kg$$

$$\sum F_x = F_f = ma_x = \left(0.056\right)\left(4.38\right) = 0.24528 \approx \boxed{0.25N}$$

♥ Technically it is the force of *kinetic* friction. We will define static and kinetic friction in a later lesson.

Flipping Physics Lecture Notes:
Introduction to Newton's Third Law of Motion

Newton's Third Law of Motion: $\vec{F}_{12} = -\vec{F}_{21}$



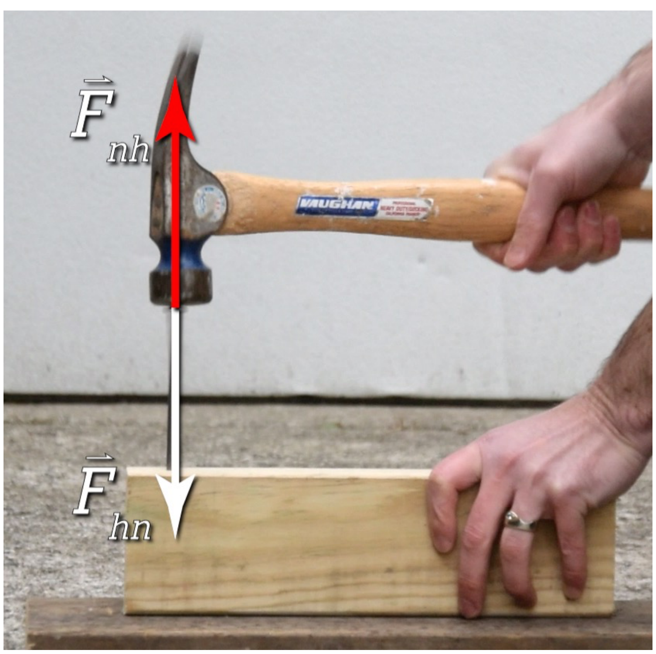
For every force object 1 exerts on object 2 there is an equal and opposite force object 2 exerts on object 1 where both forces are vectors.

For example, the force the ball exerts on my head is equal in magnitude and opposite in direction to the force my head exerts on the ball.

These two forces, $\vec{F}_{12}$ & $\vec{F}_{21}$, are called a Newton's Third Law Force Pair. They are equal in magnitude and opposite in direction. The act on two different objects and occur simultaneously.

An often quoted version of Newton's Third Law is "For every action there is an equal and opposite reaction." I do not like this version of the law because the terms "action" and "reaction" are unclear; Newton's Third Law has to do with forces not "actions." Also, the terms "action" and "reaction" imply that the two forces are not simultaneous, which is incorrect. The two forces are simultaneous. Newton's Third Law Force Pairs are sometimes referred to as "Action/Reaction Pairs".

Two more examples of Newton's Third Law Force Pairs:



Flipping Physics Lecture Notes:
A Common Misconception about Newton's Thrid Law Force Pairs
(or Action-Reaction Pairs)

Newton's Third Law of Motion: $\vec{F}_{12} = -\vec{F}_{21}$

For every force object 1 exerts on object 2 there is an equal and opposite force object 2 exerts on object 1 where both forces are vectors.

From the Free Body Diagram of the book resting on the table: (Force Normal up and Force of Gravity Down)

$$\sum F_y = F_N - F_g = ma_y = m(0) = 0 \Rightarrow F_N = F_g \Rightarrow \vec{F}_N = -\vec{F}_g$$

- The book is at rest so the acceleration of the book in the y-direction is zero.
- $F_N = F_g$ is just the magnitudes of the two forces.
- From the Free Body Diagram we know:
  - The Force Normal is up and positive
  - The Force of Gravity is down and negative
  - Therefore: $\vec{F}_N = -\vec{F}_g$

The Force Normal and the Force of Gravity are equal in magnitude and opposite in direction; however, they are not a Newton's Third Law Force Pair because the two force act on the same object. Newton's Third Law Force Pairs always act on two different objects.

The Force Normal is the force the table applies upward on the book. Therefore, the Newton's Third Law force that makes the Force Pair with the Force Normal is the force the book applies downward on the table.

The Force of Gravity is the force the Earth applies downward on the book. Therefore, the Newton's Third Law force that makes the Force Pair with the Force of Gravity is the force the book applies upward on the Earth.