Forces I

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Forces I

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Introduction to Forces

Introduction to Forces

Kinematics is the study of how objects move. For the most part, the motion is restricted to stepwise constant acceleration. This allows the use of Kinematic Procedures to solve more realistic problems.

The restriction to constant acceleration can be relaxed if we allow for the use of Calculus in the analysis of how objects. If the acceleration is not constant, the net force will also then vary in time or position. An important example of this is Simple Harmonic Motion (SHM).

Dynamics is the study of why objects change their motion - forces. This is ultimately what the study of Physics is all about – the understanding of the four (that we know of) fundamental forces of nature; how these fundamental forces between two objects can lead to macroscopic forces, like friction, that act on macroscopic objects, etc.

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Introduction to Forces

Introduction to Forces

For completeness, the four fundamental forces of which we have knowledge are:

- **Gravitational force**
  - Force between two objects that have mass mediated by gravitons
- **Electromagnetic force**
  - Force between two objects that have electric charge mediated by photons
- **Weak Nuclear force**
  - Force responsible for radioactive decay mediated by W and Z bosons
- **Strong Nuclear force**
  - Force that holds protons and neutrons together, resulting in atomic nuclei and is responsible for fusion and fission, and mediated by gluons

There may be more – for instance, our experience of dark energy and dark matter may be the result of a fifth force about which we have no knowledge as yet.

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Introduction to Forces

Introduction to Forces

Most students are, to some extend, conversant with the basic ideas of forces from their own past experiences. Before starting in on Newton's Laws, the following question sheet helps to focus the thoughts of the students on the central idea, setting the stage for a more thoughtful discussion of Newton's Laws.

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Force Introduction Questions

1. A hockey puck is slid, flat side down, across the floor. It stops relatively quickly. Why does it stop?

2. A hockey puck is slid, flat side down, across the ice at an extremely large hockey rink.
   a) What happens?

   b) Why?

   c) Why does this differ from the first question?

3. A very large cruse ship is sailing at constant speed when suddenly the engine fails.
   a) What happens?

   b) Why?

4. The Starship Enterprise spies some cosmic phenomenon. It launches a probe to investigate. The probe uses traditional chemical propellent. Halfway to the target, the engine on the probe fails.
   a) What happens to the probe?

   b) Why?

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Force Introduction Questions

1. A hockey puck is slid, flat side down, across the floor. It stops relatively quickly. Why does it stop?

   Friction opposes the motion, bringing the puck quickly to rest

2. A hockey puck is slid, flat side down, across the ice at an extremely large hockey rink.
   a) What happens?

   It slides a longer distance than for question 1 before it stops

   b) Why?
   Friction opposes the motion

   c) Why does this differ from the first question?
   There is less friction since it is on ice, so it takes longer to stop

3. A very large cruse ship is sailing at constant speed when suddenly the engine fails.
   a) What happens?
   The ship eventually stops, but only after a very long distance

   b) Why?

   The ships is extremely massive, so it takes a very long tome to stop

4. The Starship Enterprise spies some cosmic phenomenon. It launches a probe to investigate. The probe uses traditional chemical propellent. Halfway to the target, the engine on the probe fails.
   a) What happens to the probe?
   Moves with constant non-zero velocity

   b) Why?
   There is no force acting, so there is no acceleration, so the velocity remains constant

In my classes, perhaps even before discussing forces at all, I have my students answer these questions. The responses given here are representative of what some of the more "science literate" students might offer up. In a group discussion afterwards, the class will easily tend toward these. It is a good way to focus them as an intro to the three laws of motion.

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Newton's Three Laws of Motion

Newton's First Law

The "State of Motion" of an object does not change unless acted upon by an OUTSIDE (net) force

- **State of motion is a fancy way of saying velocity**
  - **If using "velocity", this law is usually broken into two parts**
    - ✓ **Objects in motion**
    - ✓ **Objects at rest**
- **This is a qualitative statement**
- **Sometimes referred to a "Law of Inertia"**
  - **As a (<u>negative</u>) result:**
    - ✓ **Inertia is often misinterpreted as the "cause" of something:**
      - **Common <u>unfortunate</u> example: "Inertia is what keeps an object moving in a straight line"**
      - **Common <u>unfortunate</u> example: "Inertia is what keeps an planet moving in a circular orbit"**
    - ✓ **Forces "cause" – Inertia does not!**

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Newton's Three Laws of Motion

Newton's Second Law

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

This is a quantitative vector equation

- **Each coordinate direction must be considered separately**
- **Encompasses Newton's First Law:**
  - $F_{net} = 0 \leftrightarrow a = 0 \leftrightarrow v = constant$
  - $F_{net} \neq 0 \leftrightarrow a \neq 0 \leftrightarrow v \neq constant$
- **m is the Inertia, or Inertial Mass**
  - **Although they are equal in value (this is essentially Einstein's equivalency principle), the inertial mass and the gravitational mass are conceptually different**
- **gravitational mass, m, is what will be found in the gravitational force equations mg or $G\frac{m_1 m_2}{r^2}$**

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Newton's Three Laws of Motion

Newton's Second Law

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

Qualitatively:

Inertia is resistance of an object to a change in its motion

Quantitatively:

$$m = \frac{F_{net}}{a}$$

- For a given net force, the larger the inertia, the smaller the acceleration.
- For a given acceleration, the larger the inertia, the larger the net force must be.
- It is important to keep the focus on the net force, and not, for example, ignoring friction and focusing simply on the push on an object.

Note: Since $\vec{F}_{net}$ and $\vec{a}$ are in the same direction, the above is true regardless of using the full equation or its components.

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Newton's Three Laws of Motion

Newton's Third Law

"***For every action there is an equal and opposite reaction***"

Newton's 1st and 2nd Laws:

- Refer to **one object**
  - on which the forces act.

Newton's 3rd Law:

- Refers to **two objects**
  - acting on each other with opposing forces
  - these forces
    - equal in magnitude and
    - opposite in direction.

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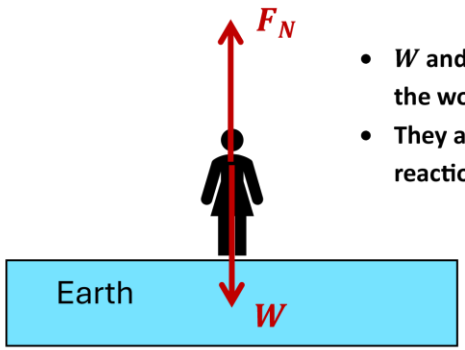
Newton's Laws - Examples

- **Second vs. Third Law**

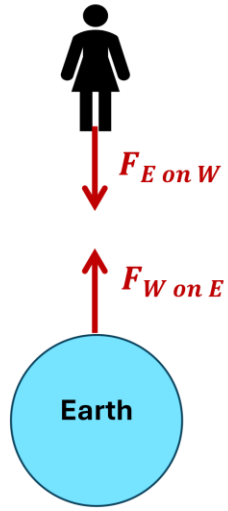
2nd vs. 3rd Law Comparison

Look at 2 forces:

- **Weight (W)** = force exerted by the Earth on an object
- **Normal Force (F_N)** = force exerted by surface on object keeping object from going through the surface



- W and F_N are 2 different forces acting on the woman (one object)
- They are equal and opposite but NOT action-reaction forces



- force exerted by the Earth on the woman $F_{E\ on\ W}$
- force exerted by woman on the Earth $F_{W\ on\ E}$
- These ARE action-reaction forces acting between two objects

There are two hidden forces in the case at the top. W is the same as $F_{E\ on\ W}$. $F_{W\ on\ E}$ would not normally be shown.

The normal force F_N Is the normal force of the Earth on the woman, but it is opposite and equal to the normal force exerted by the woman on the Earth which is also not normally shown.

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Newton's Laws - Examples

- **Third Law**
- **Penguin Walk**

Newton's Third Law Examples:
action-reaction pairs

Starting from rest, how can we walk forward?



Suppose you are on very slippery ice?

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Newton's Laws - Examples

- **Third Law**
- **Penguin Walk**

Newton's Third Law Examples: action-reaction pairs

Starting from rest, how can we walk forward?

Somehow, you need to arrange for a force to push you forward.



Suppose you are on very slippery ice?

Notice the claws on the feet!

How?

You push the ground to the right,
the ground pushes you to the left!

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Newton's Laws - Examples

- **Third Law**
- **Tug-of-War**

Tug-of-War

This is a very good, and fun, class activity, if managed properly and safely:

- Plenty of space is needed
- Always one-on-one
  - Teams are too hard to control behaviors
- The tugs are to be constant pulling forces by both contestents
  - no jerking
- Recommended – two events
  - Two "strongest"
  - "Strongest" vs "Smallest"
  - Personally, I was almost always larger than any of my students, so I would have the class choose their champion as my challenger, which I always "won" and I would then pick one of the smallest students in a second bout to highlight the difference between the two cases

Alternatively, it is easy to find videos of "Dad vs kids" in a tug-of-war contest. Dad will obviously "win".

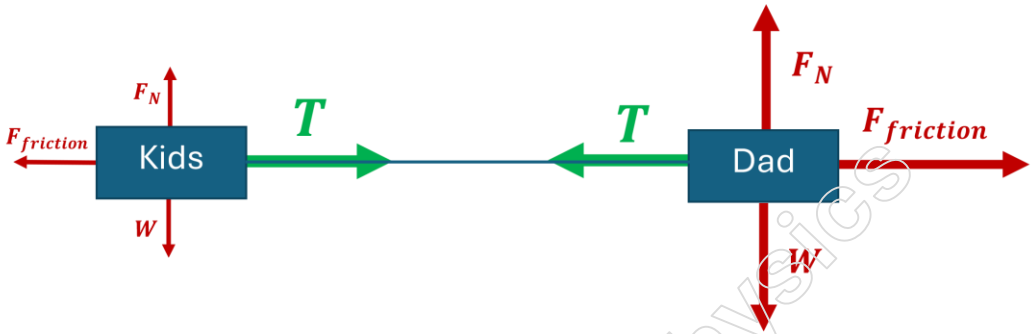
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Newton's Laws - Examples

- **Third Law**
- **Tug-of-War**

Tug-of-War Analysis



Results:

It is always a tie!

The two tensions T are an action-reaction pair. Both sides pull just as hard, regardless of who wins.

The friction force is proportional to the normal force which is equal to the weight. Since Dad weighs more that the kids, the force of friction on Dad is bigger than the force of friction on the Kids. The net force on Dad is to the right and the net force on the Kids is to the right. Dad wins!

Dad and Kids pulled just as hard. That part is a tie!

Dad wins because he pushed against the ground more than the kids!

(And therefore, the ground pushes on Dad more than the Kids!)

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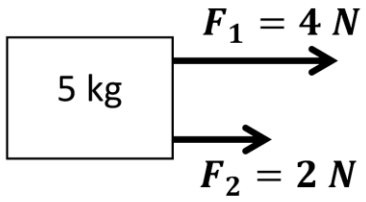
Newton's Laws - Examples

- **Second Law**

Newton's Second Law Examples:

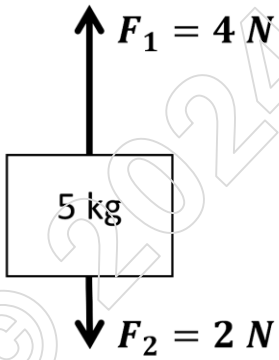
$$F_{net} = ma$$

Find a



$$F_{net} = ma$$
$$4 + 2 = (5)a$$
$$6 = 5a$$
$$a = 1.2\ \frac{m}{s^2}\ \textit{to right}$$

Find a



$$F_{net} = ma$$
$$4 - 2 = (5)a$$
$$2 = 5a$$
$$a = 0.4\ \frac{m}{s^2}\ up$$

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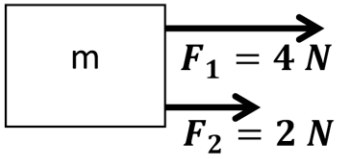
Newton's Laws - Examples

- **Second Law**

Newton's Second Law Examples:

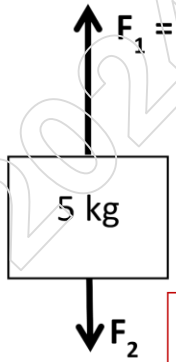
$$F_{net} = ma$$

Find m if $a = 2.0\ \frac{m}{s^2}$ to the right



$$F_{net} = ma$$
$$4 + 2 = m(2)$$
$$6 = 2m$$
$$m = 3\ kg$$

Find F_2 if $a = 2.0\ \frac{m}{s^2}$ down



$$F_{net} = ma$$
$$4 - F_2 = 5(-2)$$
$$4 - F_2 = -10$$
$$F_2 = 14\ N$$

The positive direction is explicitly downwards, so both F_2 and a are negative.

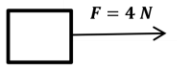
Yes – F_2 is larger than F_1, even though the diagram does not show them that way - purposefully. Since the acceleration is down, the net force must be down, and F_2 must be larger than F_1. One should not assume that vectors are drawn to scale.

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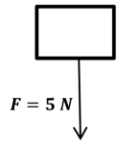
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Newton's Law Worksheet

Given Newton's Law, $F_{net} = ma$, and the diagrams below, find the missing value for the force (F), mass (m), or acceleration (a). [Although a is a vector, you do not need to specify the direction here.]

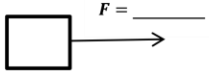


$m = 2\ kg$ $a =$ _____

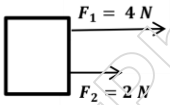


$m =$ _____

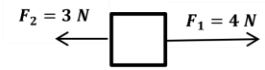
$a = 10\ \frac{m}{s^2}$



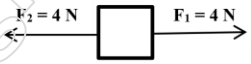
$m = 2\ kg$ $a = 6.5\ \frac{m}{s^2}$



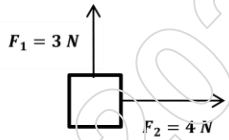
$m = 2\ kg$ $a =$ _____



$m = 3\ kg$ $a =$ _____

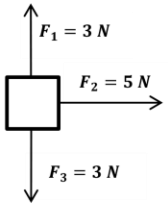


$m = 1\ kg$ $a =$ _____



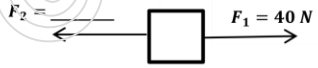
$m = 10\ kg$

$a =$ _____

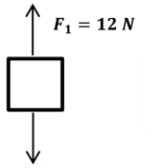


$m =$ _____

$a = 6\ \frac{m}{s^2}$



$m = 3\ kg$ $a = 6\ \frac{m}{s^2}$



$m =$ _____

$a = 0$

$F_2 =$ _____

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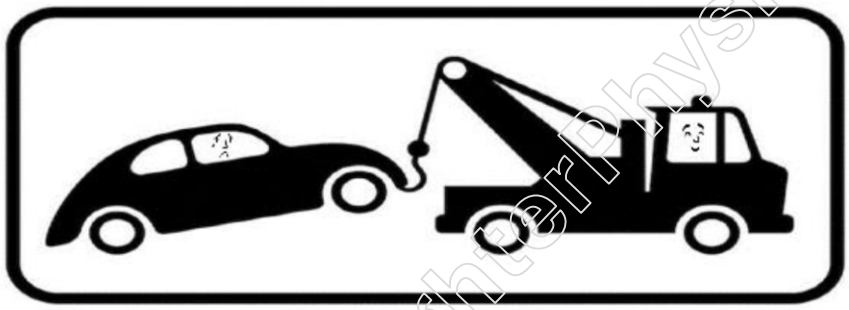
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Newton's Law Worksheet

Student Practice Blank

General Procedure for any Force Problem

General Force Procedures



What is the above sketch about?

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General Procedure for any Force Problem

General Force Procedures



What is the above sketch about?

Looking at the sketch above, we see a tow truck towing a car. Any problem is probably about the car.

Whatever question is asked, we will be using Newton's 2nd Law, which is inherently a vector equation. So, we will need to find the components of all the forces acting. We will also need to deal with the acceleration of the car.

The forces acting should be obvious to all students. In this case, there is the normal force acting upwards on the car, the weight of the car downwards, friction opposing the forward motion of the car, and the tension in the cable pulling the car upwards and to the right.

The procedure developed here is applicable to the vast majority of force problems that students will face. The graphic organization automatically decomposes the vector problem into two simultaneous scalar problems.

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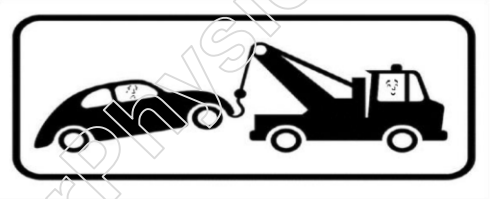
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General Force Procedures

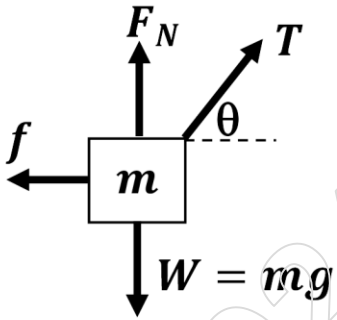
General Procedure for any Force Problem

Step 1:

Create Free-Body-Diagram



FBD:



- Mass in box
- Attach force vectors
  - name
  - direction
  - formula, if appropriate
  - values, if known

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General Force Procedures

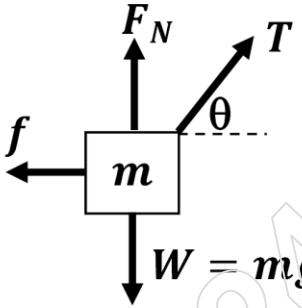
General Procedure for any Force Problem

Step 1:

Create Free-Body-Diagram



FBD:



- Mass in box
- Attach force vectors
  - name
  - direction
  - formula, if appropriate
  - values, if known

The standard FBD has a dot from which the force vectors emanate. A box, however, gives a space for the mass to be placed. Once completed, all the information from the problem is on the diagram – we do not need to search for it later.

Moreover, the boundary of the box can be interpreted as the boundary of the system. This is useful when the problem includes multiple masses, and brings consistency to our view of systems in forces, momentum, and work/energy.

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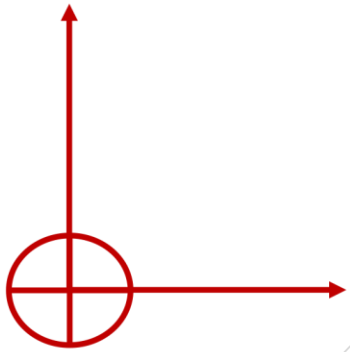
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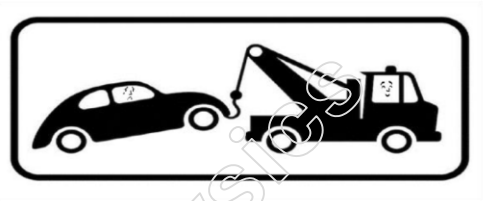
General Force Procedures

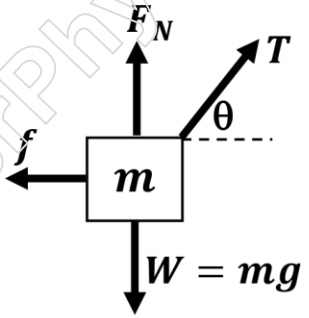
General Procedure for any Force Problem

Step 2:

Choose Positive Direction







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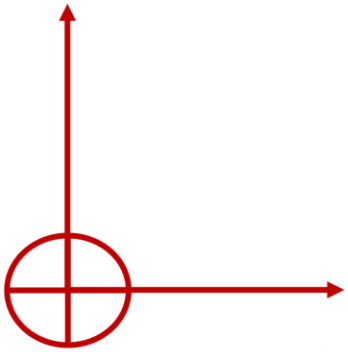
General Force Procedures

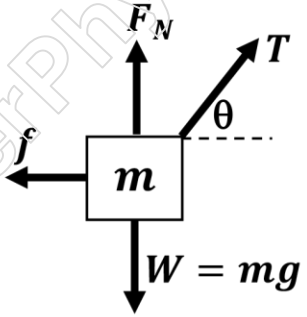
General Procedure for any Force Problem

Step 2:

Choose Positive Direction







This will determine the sign of the components for each force and the components of the acceleration.

As a general rule, the best choice for positive is the direction of the acceleration if known. Although students tend to correctly assign the sign of the force components, they will often not consider the sign of the acceleration. The choice of positive in the direction of the acceleration eliminates this common mistake.

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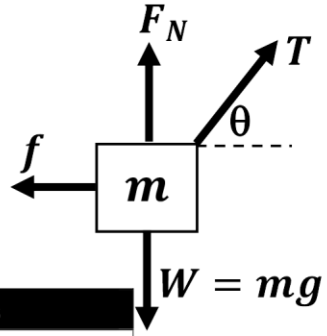
General Procedure for any Force Problem

General Force Procedures

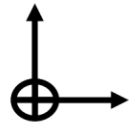


Step 3:

Create Force Table



Force	x-components	y-components
F_N	0	F_N
mg	0	$-mg$
f	$-f$	0
T	$T\cos\theta$	$T\sin\theta$



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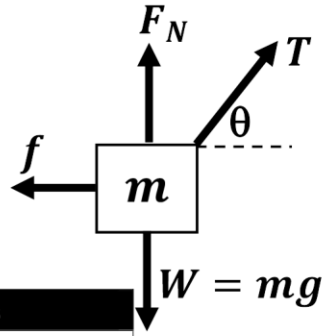
General Procedure for any Force Problem

General Force Procedures

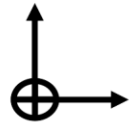


Step 3:

Create Force Table



Force	x-components	y-components
F_N	0	F_N
mg	0	$-mg$
f	$-f$	0
T	$T\cos\theta$	$T\sin\theta$



- 1st column is symbolic
  - Identifies the forces acting and corresponds to FBD
- 2nd and 3rd columns are the components of the force
  - The signs of the components are determined from the positive choice in step 2

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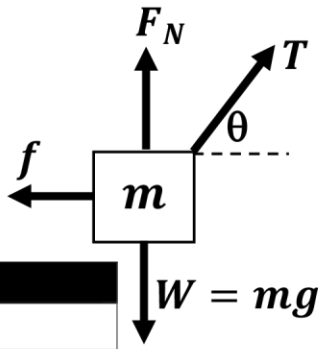
General Force Procedures

General Procedure for any Force Problem

Step 4:

Add each column





Force	x-components	y-components
F_N	0	F_N
mg	0	$-mg$
f	$-f$	0
T	$T\cos\theta$	$T\sin\theta$
F_{net}	$T\cos\theta - f$	$T\sin\theta - mg + F_N$



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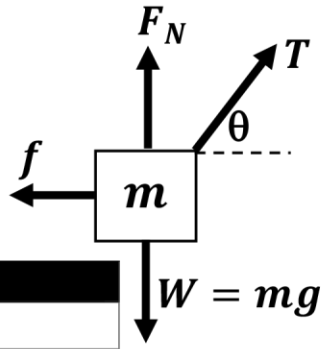
General Force Procedures

General Procedure for any Force Problem

Step 4:

Add each column





Force	x-components	y-components
F_N	0	F_N
mg	0	$-mg$
f	$-f$	0
T	$T\cos\theta$	$T\sin\theta$
F_{net}	$T\cos\theta - f$	$T\sin\theta - mg + F_N$



The 1st column is just symbolic. It will become our naked equation, Newton's 2nd law.

The 2nd and 3rd columns will become Newton's 2nd law in both coordinate directions.

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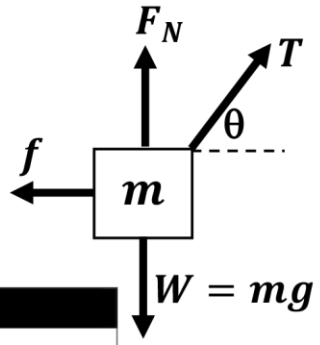
General Force Procedures

General Procedure for any Force Problem

Step 5:

Set each equation = ma





Force	x-components	y-components
F_N	0	F_N
mg	0	$-mg$
f	$-f$	0
T	$T\cos\theta$	$T\sin\theta$
$F_{net} = ma$	$T\cos\theta - f = ma_x$	$T\sin\theta - mg + F_N = ma_y$



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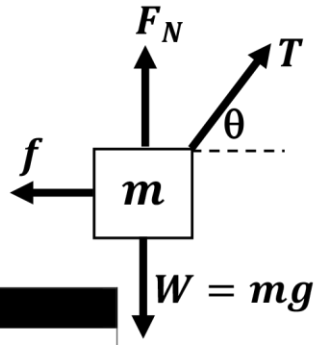
General Force Procedures

General Procedure for any Force Problem

Step 5:

Set each equation = ma





Force	x-components	y-components
F_N	0	F_N
mg	0	$-mg$
f	$-f$	0
T	$T\cos\theta$	$T\sin\theta$
$F_{net} = ma$	$T\cos\theta - f = ma_x$	$T\sin\theta - mg + F_N = ma_y$



This is the first place that we need to think about the problem.

Physically, the car does not leave the road, so $a_y = 0$ and $a_x = a$.

Typically, at this level, either $a_x = 0$ or $a_y = 0$ or both.

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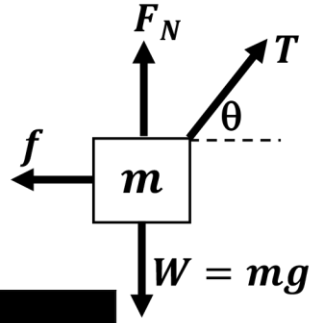
General Force Procedures

General Procedure for any Force Problem

Step 6:

Solve





Force	x-components	y-components
F_N	0	F_N
mg	0	$-mg$
f	$-f$	0
T	$T\cos\theta$	$T\sin\theta$
$F_{net} = ma$	$T\cos\theta - f = ma$	$T\sin\theta - mg + F_N = 0$



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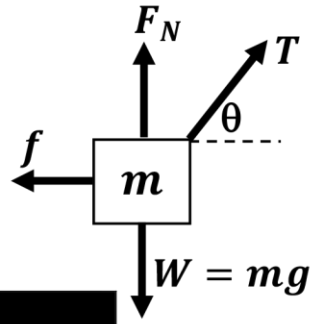
General Force Procedures

General Procedure for any Force Problem

Step 6:

Solve





Force	x-components	y-components
F_N	0	F_N
mg	0	$-mg$
f	$-f$	0
T	$T\cos\theta$	$T\sin\theta$
$F_{net} = ma$	$T\cos\theta - f = ma$	$T\sin\theta - mg + F_N = 0$





At this point you have 2 simultaneous equations to solve

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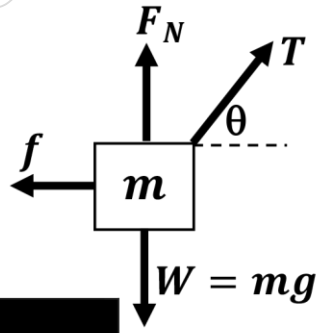
General Force Procedures

General Procedure for any Force Problem

Step Summary:

- FBD
- Positive Direction
- Create Chart
- Add Columns
- $= ma$
- Solve





Force	x-components	y-components
F_N	0	F_N
mg	0	$-mg$
f	$-f$	0
T	$T\cos\theta$	$T\sin\theta$
$F_{net} = ma$	$T\cos\theta - f = ma$	$T\sin\theta - mg + F_N = 0$



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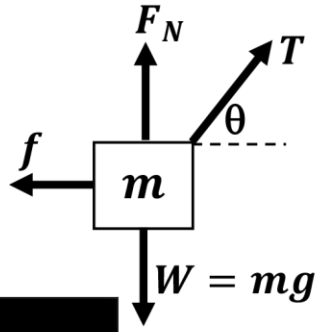
General Force Procedures

General Procedure for any Force Problem

Step Summary:

- FBD
- Positive Direction
- Create Chart
- Add Columns
- $= ma$
- Solve





Force	x-components	y-components
F_N	0	F_N
mg	0	$-mg$
f	$-f$	0
T	$T\cos\theta$	$T\sin\theta$
$F_{net} = ma$	$T\cos\theta - f = ma$	$T\sin\theta - mg + F_N = 0$



Notice – no question has been asked.
Simply based on the sketch of the problem, after the process is complete the answer to whatever question might be asked is somewhere on this page.

Each step in this process tackles one task that is applied to completion before starting the next. Based on where a student makes a mistake, it is easy to identify where the student needs help.

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Elevator Quiz

1. An elevator with 3 passengers, total mass of 10000 kg, is sitting at the 1st floor waiting for someone to press a button to move. What is the tension in the cable holding the elevator at rest?

2. Will the tension increase, decrease, or remain the same if the elevator begins to rise to the 2nd floor?

3. Will the tension increase, decrease, or remain the same as the elevator slows to the 2nd floor?

4. Will the tension increase, decrease, or remain the same if the elevator begins to lower to the basement?

5. Will the tension increase, decrease, or remain the same if the elevator begins to slow to the basement?

6. If the acceleration towards the basement is 2.5 m/s^2, what is the tension in the cable?

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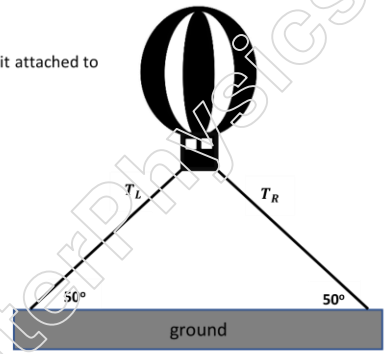
Elevator Quiz

Student Practice Blank

Hot Air Balloon

The diagram at right represents a balloon just before take-off. The balloon's basket is attached to the ground by two ropes. There is a vertical buoyant force $F_B = 2150\ N$ acting upwards on the basket due to the balloon. The total mass of the balloon+bucket is $195\ kg$.

1. What is the magnitude of the net force acting on the bucket when it attached to the ground?



2. Calculate the tensions T_R and T_L while the balloon is tethered to the ground.

3. The tether lines are now cut and the balloon accelerates upwards. Calculate the acceleration of the bucket immediately after the tether lines are cut.

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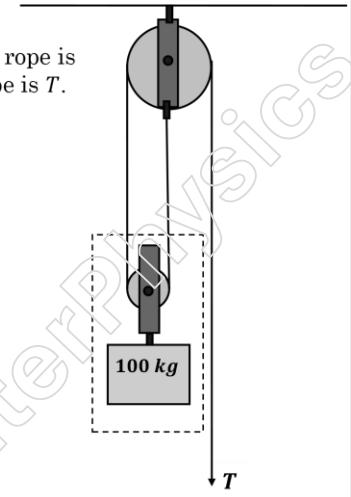
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Hot Air Balloon

Student Practice Blank

Hoist Worksheet

A pulley system is constructed as shown at right.
A force T pulls downward on the rope. Assume that the rope is massless, in which case, the tension throughout the rope is T.



1) What force T must be applied to raise the 100 kg mass upwards at a constant speed?

2) What force T must be applied to lower the 100 kg mass with an acceleration of 2 $\frac{m}{s^2}$

Hint: Consider the 100 kg mass and the lower pulley as a single unit.

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Hoist Worksheet

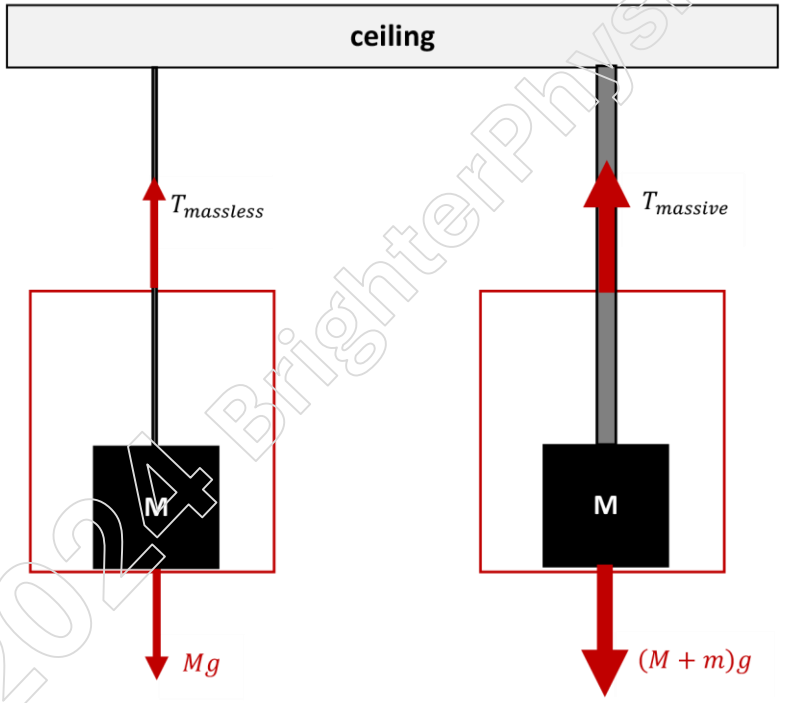
Student Practice Blank

Massive
vs
Massless
Rope

Effect
On
Tension

Massive vs Massless Rope

Consider two ropes suspended from a ceiling, each attached to an identical mass at the end.
The rope on the left is very light, or massless.
The rope on the right has mass that cannot be ignored.



m = mass of rope enclosed in FBD

Since $a = 0, T_{massless} = Mg$

The tension in the rope is the same throughout the rope.

Since $a = 0, T_{massive} = (M+m)g$

The tension in the rope is not a constant.

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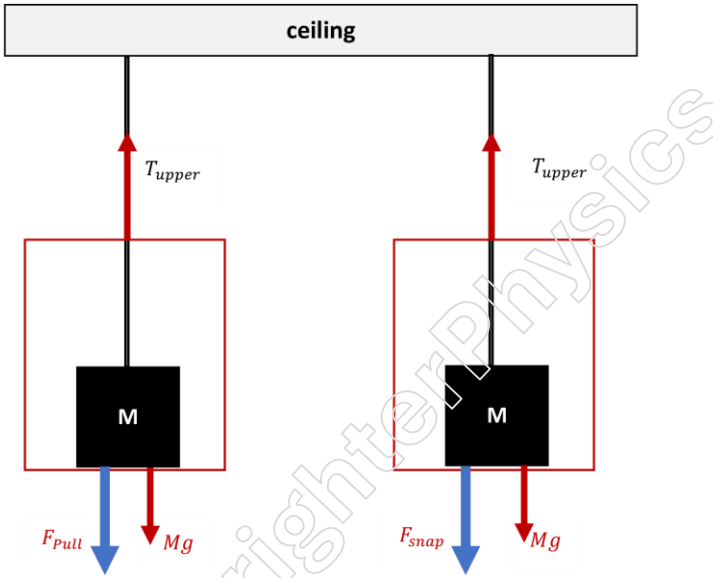
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Massive
vs
Massless
Rope

Breaking
String
Demonstration

Breaking String Demo

Consider two identical masses suspended from a ceiling on a string. A second string is attached to the bottom of each mass. This string is then pulled. Which string breaks?



If the lower string is pulled, slowly increasing the tension in the lower string, so does the tension in the upper string, since $F_{pull} + Mg - T_{upper} = 0$.

In fact, the tension will be largest near the ceiling. The string will break when the tension at any given point exceeds the tensile strength. For uniform string, this will occur in the upper string near the ceiling.

Physically, the tension in a string comes from the stretching of the string, very much like a spring.

If the lower string is snapped with a force that is larger than the tensile strength of the string, then $F_{snap} + Mg - T_{upper} = Ma$.

T_{upper} is less than the tensile strength before the snap and will not increase until the mass M moves, which will because a is downwards when the pulse hits.

However, before the mass has time to move, the lower string breaks because the tension in the lower string exceeded the tensile strength. The upper string survives!

Pull - Video Demo:
https://youtu.be/SgJPZmDc22c?si=XiTFLtC4TL0jzyeP

Snap – Video Demo
https://youtu.be/WODTnx2Txwl?si=9N9ZnvVmgddZ6SM2

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Force Four Square

1. Ayesha horizontally pushes a $1000\ kg$ Smart Car along a flat road at a constant speed. If there is a friction force of $150\ N$ acting on the car, with what force is she pushing?	2. Bart manages to move a $300\ kg$ crate along the floor with an acceleration of $0.25\ \frac{m}{s^2}$. He pushes with a horizontal force of $200\ N$. What is the force of friction acting on the crate?
3. Ever the physics experimentalist, Chiyo stands on a scale which is on a skate board which rolls along a flat surface with a constant speed. To make things even more interesting, she is holding onto a helium balloon that pulls upwards with a force of $2.0\ N$. Chiyo has a mass of $42\ kg$. What is the reading of the scale? [The scale reads the normal force F_N.]	4. Thankfully remembering his parachute, Derek jumps out of a plane at $10000\ ft$. Suppose that he has a mass of $75\ kg$. What is the upward force exerted by the parachute on him when he has an acceleration of $2.0\ \frac{m}{s^2}$ downwards.

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Force
Four
Square

Student Practice
Blank

Force Procedures Worksheet

1. A $1500\ kg$ car is pulled along a level road by a tow truck. The cable between the tow truck and car makes an angle of $37°$ from the horizontal. Friction between the car and the road is $2200\ N$. The truck accelerates with a rate of $2.0\ \frac{m}{s^2}$.
   a) What is the tension, T, in the cable?
   b) What is the Normal Force, F_N?

2. You have finally made the big time. You have landed a summer job with your aunt's landscaping company. You push a lawn mower along a level field of tall grass. The lawn mower has a weight of $500\ N$. Unfortunately, the mower is not self-propelled. Friction between the mower and the grass is $100\ N$. You push along the handle [note that the direction is inward toward the mower] which makes an angle of $30°$ from the horizontal. You manage to push so that the mower moves with constant speed.
   a) With what force, F_{push}, do you push the mower?
   b) What is the Normal Force, F_N?

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Force Procedures Worksheet

Student Practice Blank – page 1

Force Procedures Worksheet

3. A fully loaded Estes rocket has a typical mass at launch of about $80\ g$. (Convert to kg.) An Estes rocket produces an initial upwards thrust (force) of $6\ N$. What is the acceleration of the rocket immediately after launch?

4. A $200\ kg$ gorilla stands on a skateboard holding a bouquet of helium balloons. The balloons exert a $150\ N$ upward force. The gorilla is pulled by a rope angled at $30°$ above the horizontal. Friction between the skateboard and the ground is $250\ N$. The force of friction is sufficient to keep the gorilla from accelerating.

a) What is the tension, T, in the rope?

b) What is the Normal Force, F_N, acting on the gorilla?

5. A $65\ kg$ daredevil parachutes from a helicopter. Assume that, before the parachute is opened, the upward force of air friction is given by the expression $F_{air} = 0.15v^2$, where v is the speed in $\frac{m}{s}$, and F_{air} is in N.

a) Immediately after she jumped, what was her acceleration?

b) What is her acceleration when her speed is 20 m/s? (Is she speeding up or slowing down?)

c) What is her acceleration when her speed is 40 m/s? (Is she speeding up or slowing down?)

d) What is her acceleration when her speed is 65 m/s? (Is she speeding up or slowing down.?)

e) What is her speed when her acceleration becomes 0?

f) What is her speed 5 seconds after part e? (Is she speeding up or slowing down or what?)

Draw the Free Body Diagram for an arbitrary speed v.
Then write down the resulting equation.
Then you just need to put in the values from the specific questions into that equation and solve. Easy?

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Force Procedures Worksheet

Student Practice Blank – page 2

Multiple Masses

Multiple Masses

Often multiple masses are presented in a problem. In kinematics problems, the motion of each mass is generally independent of the others, and so we treated them separately resulting in simultaneous equations.

In force problems, these masses are often physically coupled together in some way. Even when they are not physically connected, at times it is convenient to treat them in independent groupings. This is where the benefit of creating a box as part of the FBD becomes evident.

Let's look at Newton's 2nd Law $\vec{F}_{net} = m\vec{a}$ more closely.

- ***$\vec{F}_{net}$ is the vector sum of all the (external) forces acting on the system (internal forces cancel in pairs)***
- ***m is the mass of the system***
- ***$\vec{a}$ is the acceleration of the center-of-mass of the system***

The box drawn for the FBD can be considered as defining the system being considered. A more suggestive way to write the 2nd law of the system corresponding to the FBD is then:

$$\vec{F}_{net} = m_{system}\vec{a}_{cm}$$

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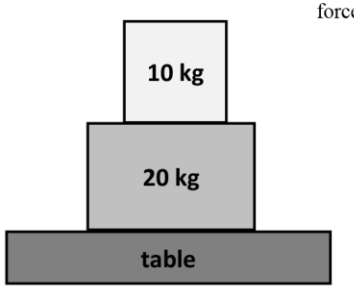
Multiple Masses - an example

Multiple Mass Example

A 10 kg box is placed on top of a 20 kg box which is placed on a table

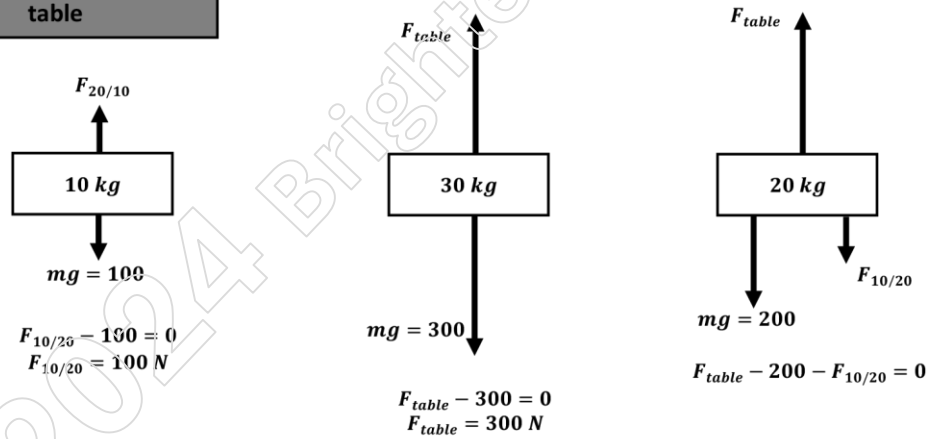
- Determine the normal force ($\boldsymbol{F_{table}}$) that the table exerts on the 20 kg box
- Determine the normal force ($\boldsymbol{F_{20/10}}$) exerted by the 20 kg box on the 10 kg box

Note, $\boldsymbol{F_{10/20}}$ and $\boldsymbol{F_{20/10}}$ are the action-reaction normal forces acting on the 10 and 20 kg boxes



There are 2 masses to consider.
We can consider the two masses separately, and also the combined pair.

- A total of 3 separate FBDs that can be considered



The $F_{10/20}$ action-reaction pair is not present in the center FBD. They are forces that start on one mass and ends on the other within the boundary of the system – they do not cut through the boundary of the system and so are not included. [Technically they are part of the vector sum, but they cancel in the vector sum as an action-reaction pair.]

The FBD for the 10 kg and the 30 kg combo are enough to solve the problem – each an independent equation.

If the FBD for the 20 kg mass is chosen, than either of the other two equations are needed to solve for both unknowns. These two equations are then dependent equations.

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Normal Force

&

Friction Force

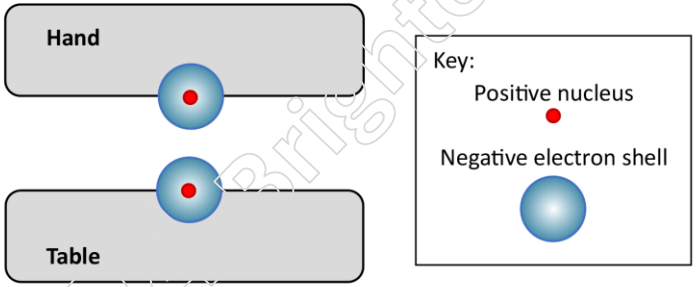
Normal Force

The Frictional Force between two solid surfaces and the Normal Force between the same two surfaces are inextricably connected.

Let's start by looking more closely at the Normal Force. If you place your hand on the table, the table exerts a force on your hand to keep your hand from passing through the surface and entering the table. Similarly, an equal and opposite force is exerted by your hand on the table so the table does not enter your hand. The source of this force is electromagnetism.

Your hand and the table are made up of atoms consisting of electrons and protons. Since like charges repel and opposite charges attract, the base interaction is very understandable but there are uncountable numbers of both.

Let's look at one atom on the bottom surface of your hand and one atom on the top surface of the table:



The protons of the hand and the table repel, the electrons of the hand and the table repel, but the electrons (protons) of the table attract the protons (electrons) of the hand. When the hand and table are far apart, the force is vanishingly small. Partly because the distance between the charged particles is large, but also because those distances are about the same, so the net attraction and net repulsion approximately cancel.

However, when the two are close together, on the order of the size of the atoms, then it is the repulsion of the electrons that dominates. [The electrostatic force is an inverse square law, similar to that for gravity.] As the distance between the electron clouds approaches zero, the repulsive force becomes infinitely large. To the extent, then, that the electron clouds do not overlap, the two surfaces cannot touch. Therefore, the two surfaces levitate. When you pound your hand on the table, the electron repulsion between the surfaces compresses your flesh, compressing your nerves, which then sends a signal of pain. Similarly, it compresses the surface of the table, which then vibrates, creating sound.

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Normal Force

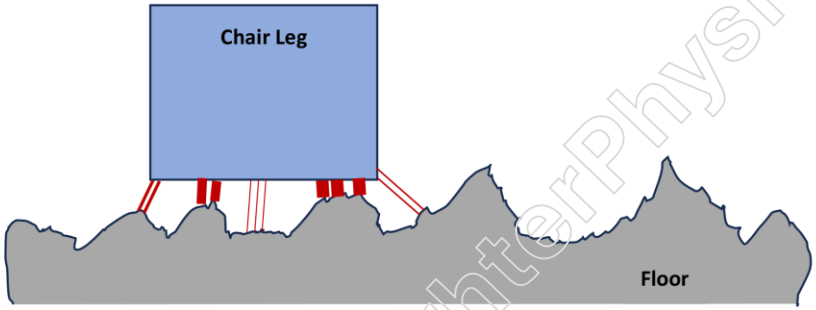
&

Friction Force

Friction Force

Given the model for Normal Forces above, if the electron clouds do not overlap, then there would be no friction. Friction is the result of adhesion between the surfaces, a result of bonding between the two surfaces, a result of electron overlap – so that the electrons of one surface are now close enough to the nuclei of the other surface so that the attraction is no longer negligible. To move one surface with respect to the other, these bonds must be broken.

Below is a highly schematic sketch of a chair leg on the floor. On the atomic level, the floor is very jagged, with deep valleys and tall peaks, as is the chair leg, but we'll ignore the unevenness of the chair leg.



In this highly simplified model, the strength of the bond (red lines in the figure) in the figure is given by the thickness of the red lines. The closer the surfaces, the stronger the bond; the farther the surfaces, the weaker the bond. In order to slide the chair, a force great enough to break those bonds must be applied.

Now what happens at this interface if extra mass is placed onto the chair. The gravitational force downwards increases, forcing the two surfaces a bit closer increasing the upward Normal Force to keep the chair from accelerating. As a result, the red bonds in the sketch become stronger, increasing the maximum frictional force. Thus we arrive at the static friction (f_{static}) relationship:

$$f_{static} \leq \mu_s F_N$$

Now, if a large enough force is exerted and the chair begins to move, the bonds in the model above break as the distance increases between those sites, while new bonds form as new sites on the surfaces approach each other. These bonds however are weaker, on average, than when the surfaces are not moving with respect to each other. The bonds in the static and the kinetic cases are essentially the same. However, no matter how slowly you try to slide a macroscopic object along another, on the atomic scale the atoms are not near to each other long enough to form a strong bond. If you think of the atomic bonds as a sharing of electrons, they are moving so fast with respect to each other that the sharing is very short lived and the bonds therefore weaker and independent of the speed of the objects. Thus we arrive at the kinetic friction ($f_{kinetic}$) relationship:

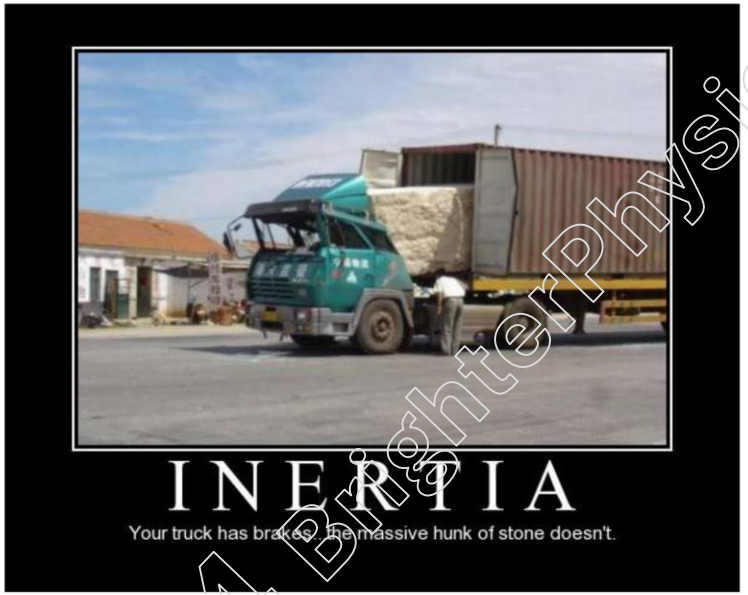
$$f_{kinetic} = \mu_k F_N$$

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Truck and Rock

Use the Physics that you have learned so far to explain what happened in the photo below

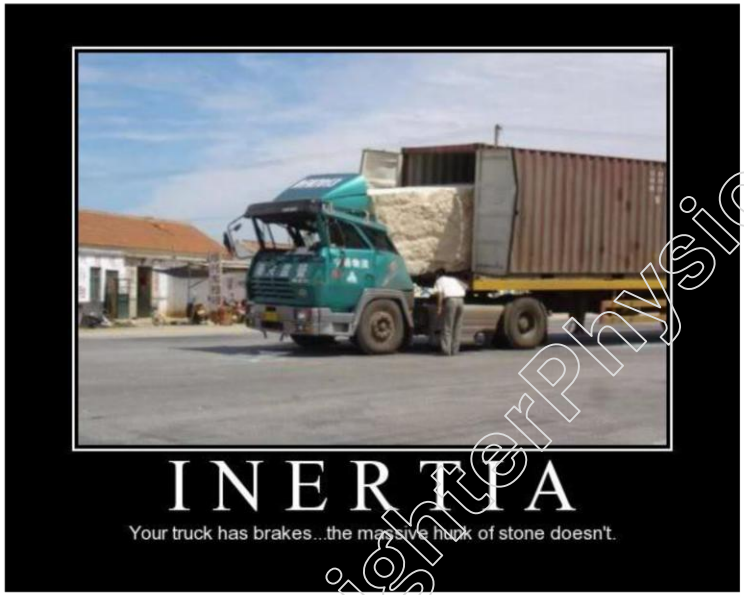


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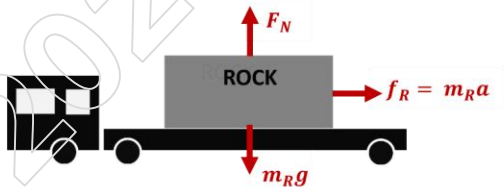
Truck and Rock

Use the Physics that you have learned so far to explain what happened in the photo below



The truck is moving to the left and applies the breaks to stop.
The acceleration a of the truck is to the right.
The force of friction in the rock is to the right.

In order for the rock to NOT slide forward, the acceration of the rock must also be the same as the truck, a, and the friction will be static friction, the maximum value of static friction will then be $\mu_s F_N$.



To NOT slide:

$$f_R = m_R a \leq \mu_s (m_R g)$$
$$a \leq \mu_s g$$

So, the driver applied his breaks to forcefully, resulting in an acceleration that was larger than $\mu_s g$. Static friction was not large enough to hold the rock in place. Kinetic friction did slow the rock down, but the truck slowed down more quickly and the rock slid forward.

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Basic Friction Questions

1. If the coefficient of kinetic friction between a 22 kg crate and the floor is 0.30, what horizontal force is required to move the crate at a steady speed across the floor?

2. A force of $35.0\ N$ is required to start a $6.0\ kg$ box moving across a horizontal concrete floor.
   a) What is the coefficient of static friction, μ_s, between the box and the floor?

   b) If the $35.0\ N$ force continues, the box then accelerates at $0.60\ \frac{m}{s^2}$. What is the coefficient of kinetic friction, μ_k?

3. Police investigators, examining the scene of a two car accident on a level road, measure $72\ m$ long skid marks of one of the cars, which nearly came to a stop before colliding. If the coefficient of kinetic friction between rubber and the pavement is $\mu_k = 0.80$, find the initial speed of the car before applying the brakes.

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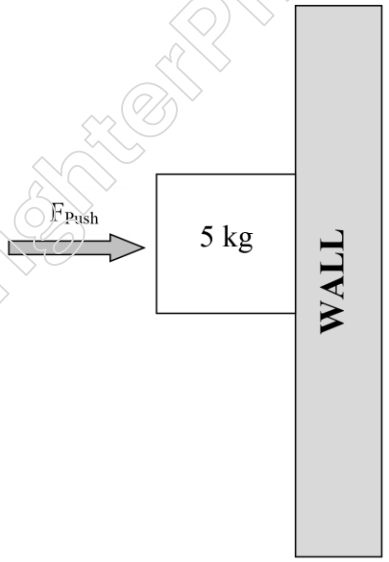
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Basic Friction Problems

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Slipping Mass

You place a 5 kg block against a rough wall. The coefficient of friction between the wall and block is $\mu = 0.25$. With what minimum horizontal force $\boldsymbol{F_{push}}$ must you push against the 5 kg block so that it does not slide down the wall.



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Slipping Mass

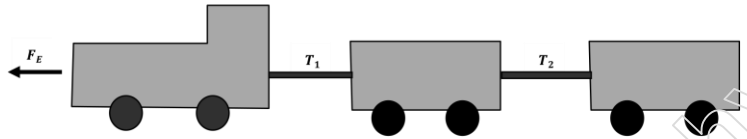
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Train with Friction

An $70{,}000\ kg$ steam locomotive pulls a $20{,}000\ kg$ tender car and a $10{,}000\ kg$ boxcar. The locomotive accelerates to the left at $2.0\ \frac{m}{s^2}$. The coefficient of friction between the wheels and the track is $\mu = 0.2$.

a) Find the tension in each of the two coupling arms: T_1 and T_2.

b) Find the forward force created by the engine, F_E.



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Train
with
Friction

Student Practice
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