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NEW JERSEY CENTER
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Algebra Based Physics

Dynamics: Laws of Motion

2017-07-06

www.njctl.org

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Intro to Dynamics: Thought Experiment

https://www.njctl.org/video/?v=piosFoket2k

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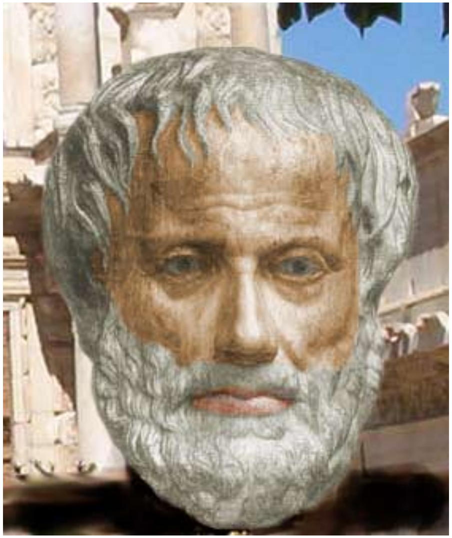
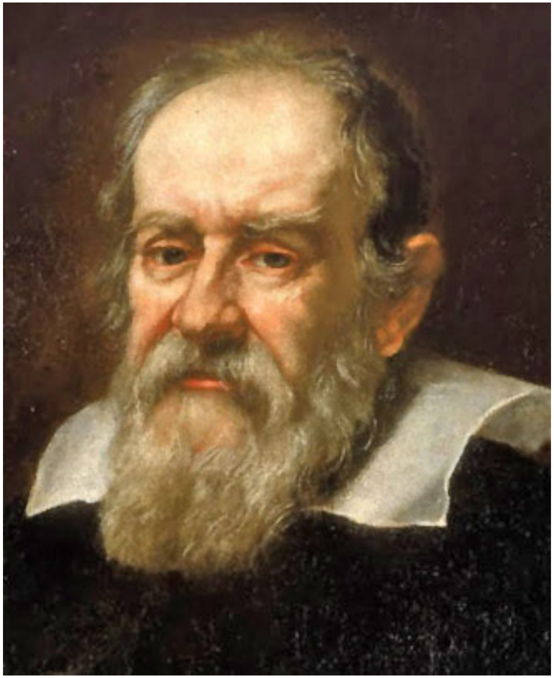
Galileo vs. Aristotle

In our experience, objects must be pushed in order to keep moving. So a force would be needed to have a constant velocity.



This is what Aristotle claimed in his in his seriesof books entitled "*Physics*", written 2400 years ago.

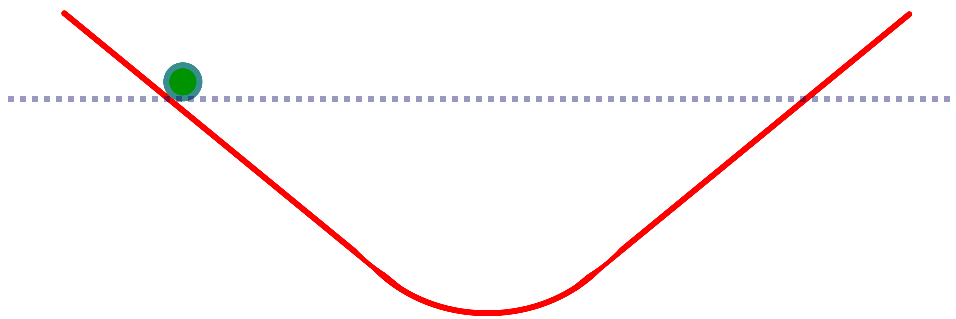
Galileo vs. Aristotle



But 400 years ago, another scientist and astronomer, Galileo, proposed the following thought experiment which revealed another perspective.

Thought Experiment

Imagine two perfectly smooth ramps connected together by a perfectly smooth surface. If a ball is let go at the top of the one ramp, *what will happen?*



Demo

Thought Experiment

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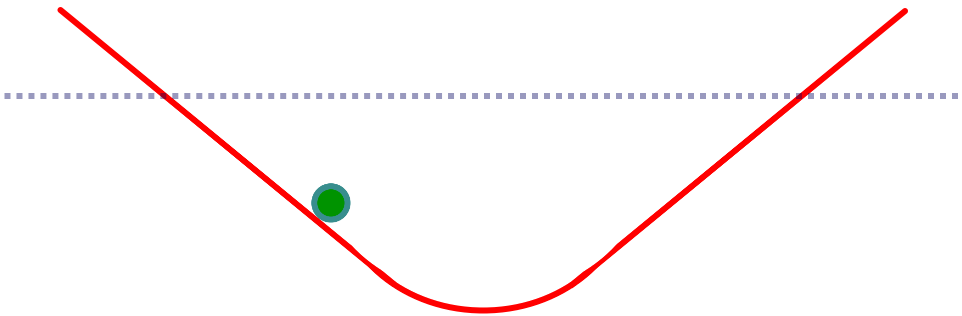

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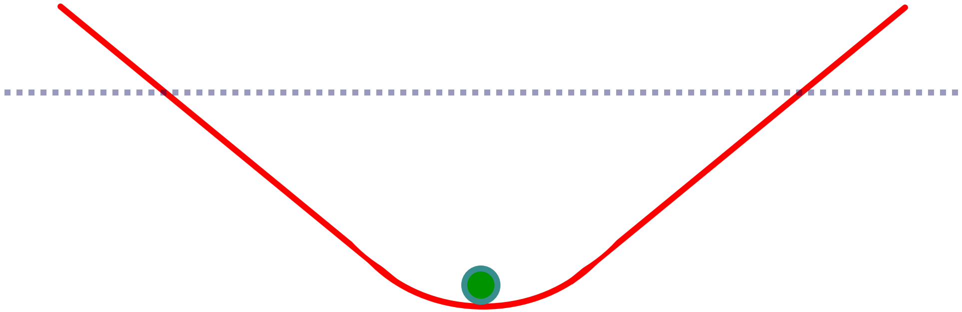

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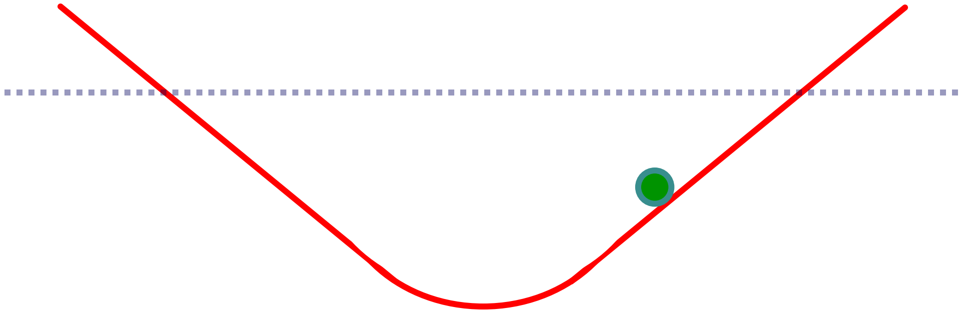
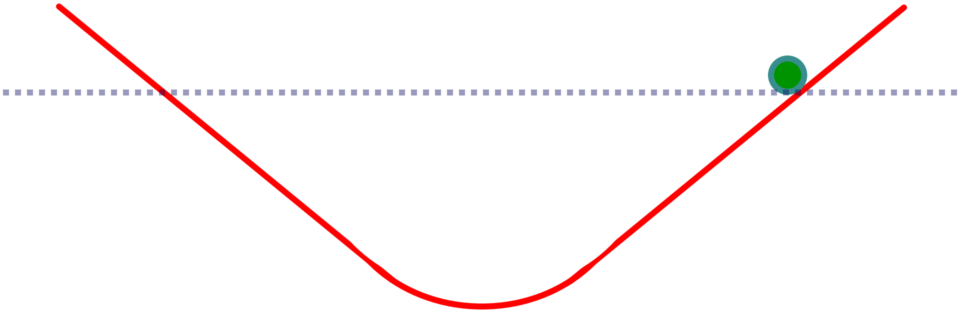


Thought Experiment

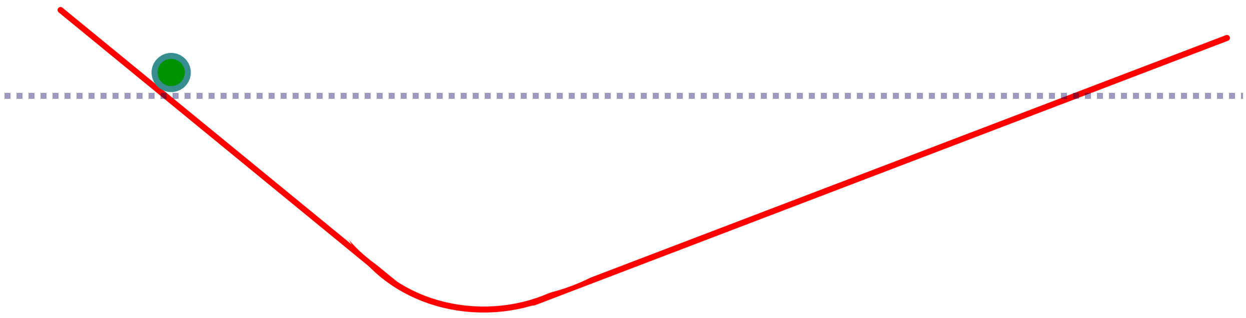
If a ball rolls down one ramp, it keeps rolling up the other side until it reaches the same height.



Thought Experiment

Now repeat that experiment, but make the second ramp less steep.

What Will Happen?



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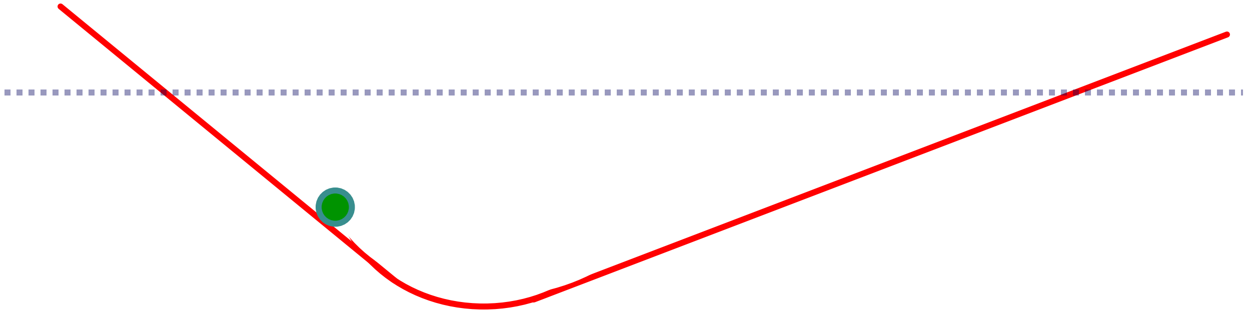

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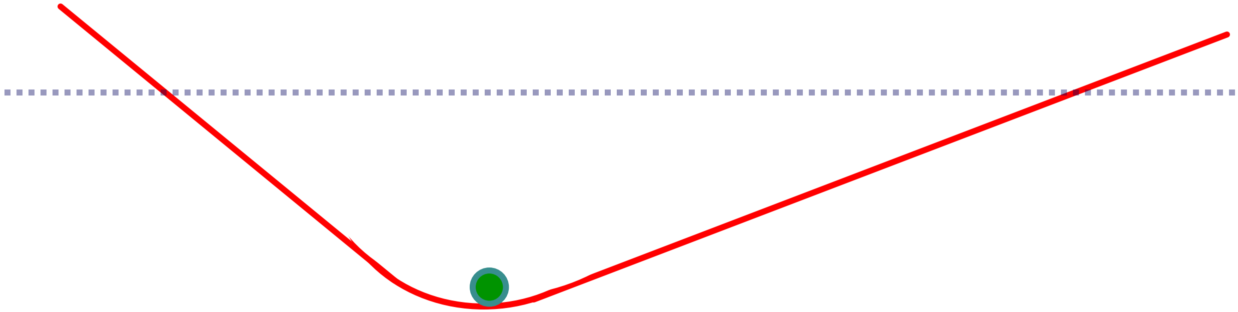

Thought Experiment

Now repeat that experiment, but make the second ramp less steep.

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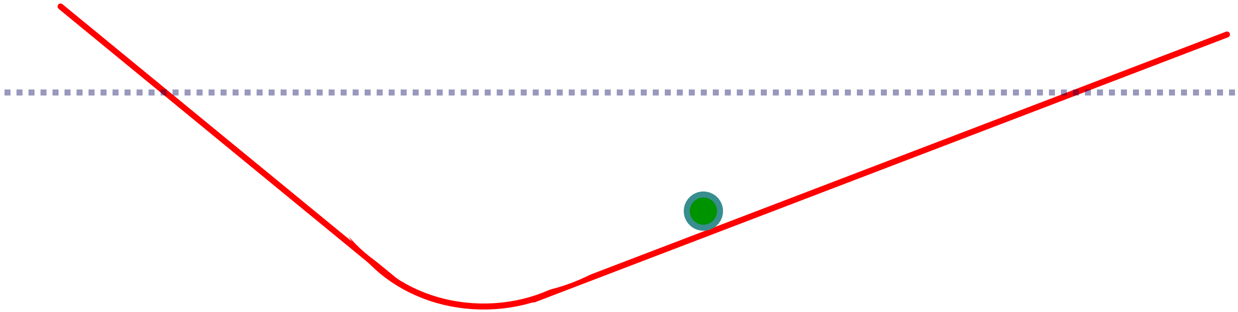
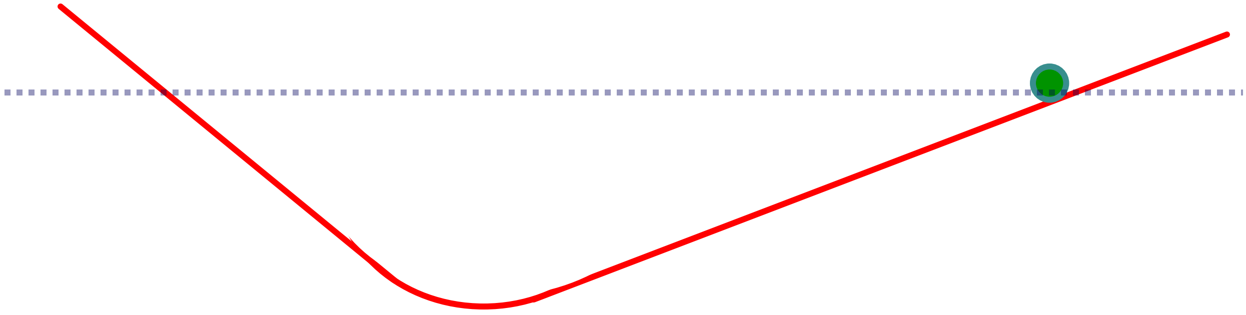


Thought Experiment

It will still keep rolling until it reaches the same height,
but it has to roll farther!



Thought Experiment

Finally, make the ramp flat.

Now what will happen?

Thought Experiment

Finally, make the ramp flat.

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Thought Experiment

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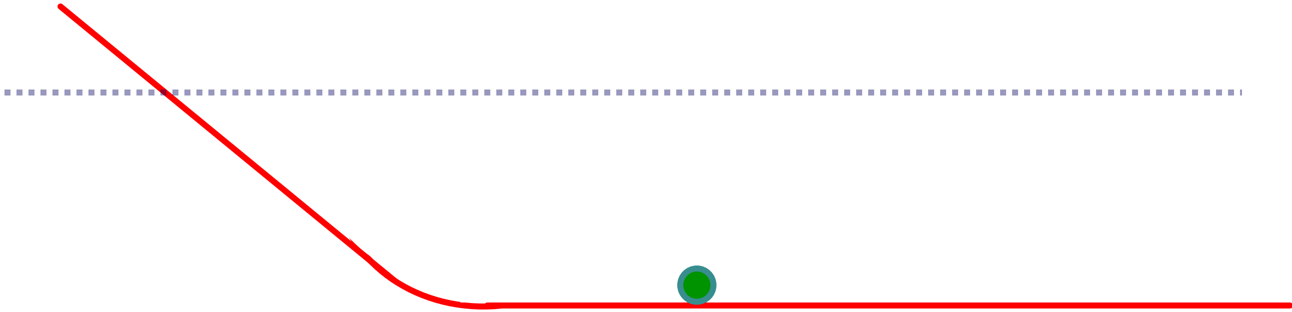
Now what will happen?



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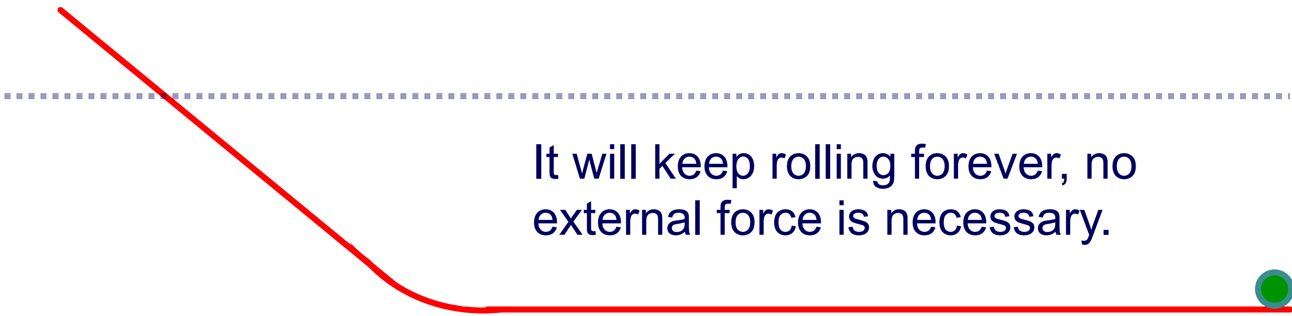
Thought Experiment

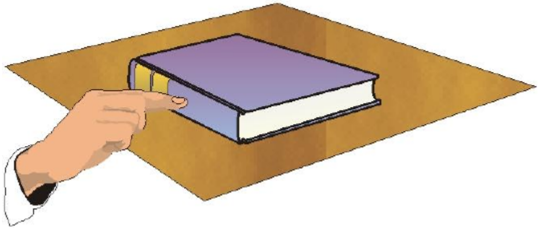


It will keep rolling forever, no external force is necessary.

Galileo vs. Aristotle

It's not that Aristotle was wrong. In everyday life, objects do need to keep being pushed in order to keep moving.

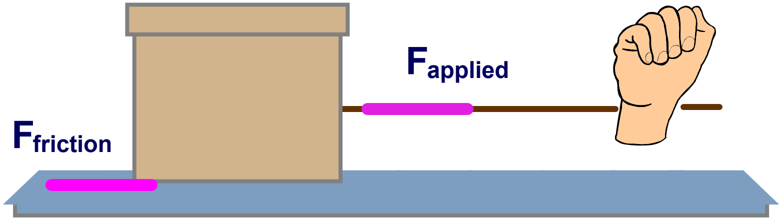
Push a book across the table. When you stop pushing, it stops moving. Aristotle is right in terms of what we see around us every day.



Force and Motion

It's just that Galileo, and later Newton, imagined a world where friction could be eliminated.

Friction represents an external force acting on the object, just as your push is an external force.



In the absence of all external forces, an object's velocity remains constant. Two equal and opposite forces have the same effect, they cancel to create zero net force.

Newton's 1st Law of Motion

Demo

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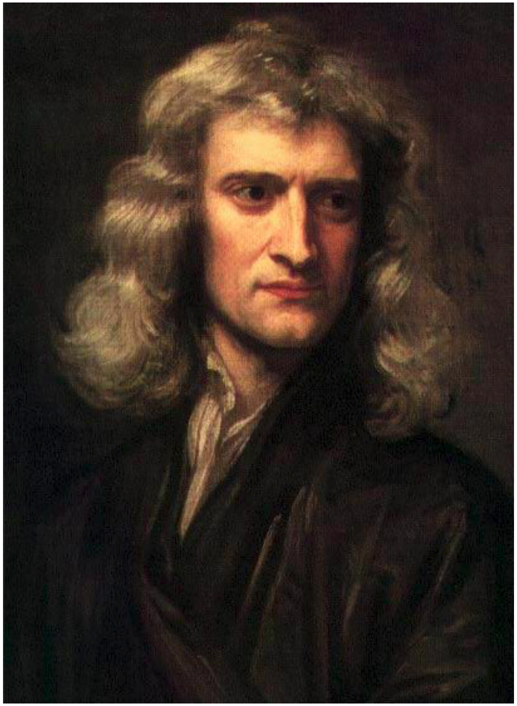
Sir Isaac Newton

Galileo's observations were more fully formed in 1687 by the "*father of physics*," Sir Isaac Newton, who called this observation "The First Law of Motion".



Newton's First Law of Motion

An object at rest remains at rest, and an object in motion remains in motion, unless acted on by a net external force.

In other words, an object maintains its velocity (both speed and direction) unless acted upon by a nonzero net force.

Having zero velocity (being at rest) is not special, it is just one possible velocity…a velocity which is no more special than any other.

A.K.A. The Law of Inertia

This law is often referred to as the "Law of Inertia." The word inertia comes from the latin word *iners* which means idle, or lazy.

Inertia is the tendency of an object to resist any change in motion.

Demo

1 In the absence of an external force, a moving object will

- A stop immediately.
- B slow down and eventually come to a stop.
- C go faster and faster.
- D move with constant velocity.
- E I need help

Answer

https://www.njctl.org/video/?v=OD4bbGZt8A0

2 When the rocket engines on a spacecraft are suddenly turned off while traveling in empty space, the starship will

- A stop immediately.
- B slowly slow down, and then stop.
- C go faster and faster.
- D move with a constant velocity.
- E I need help

Answer

https://www.njctl.org/video/?v=QJe6U8IeEuo

3 When you sit on a chair, the net external force on you is

- A zero
- B dependent on your weight.
- C down.
- D up
- E I need help

Answer

https://www.njctl.org/video/?v=ePxygnhYdMA

4 A rocket moves through empty space in a straight line with constant speed. It is far from the gravitational effect of any star or planet. Under these conditions, the force that must be applied to the rocket in order to sustain its motion is

- A equal to its weight.
- B equal to its mass.
- C dependent on how fast it is moving.
- D zero.
- E I need help

Answer

https://www.njctl.org/video/?v=TdULPDq1NuA

5 You are standing in a moving bus, facing forward, and you suddenly fall forward. You can infer from this that the bus's

- A velocity decreased.
- B velocity increased.
- C speed remained the same, but it's turning to the right.
- D speed remained the same, but it's turning to the left.
- E I need help

Answer

https://www.njctl.org/video/?v=zf8-qu0Kw-o

6 You are standing in a moving bus, facing forward, and you suddenly move forward as the bus comes to an immediate stop. What force caused you to move forward?

- A gravity
- B normal force due to your contact with the floor of the bus
- C force due to friction between you and the floor of the bus
- D no force
- E I need help

Answer

https://www.njctl.org/video/?v=jRdPVvhhrr8

Inertial Reference Frames

Newton's laws are only valid in inertial reference frames:

An inertial reference frame is one which is not accelerating or rotating. It is an area in which every body remains in a state of rest unless acted on by an external unbalanced force.

Inertial Reference Frames

When your car accelerates, it is not an inertial reference frame.

This is why a drink on the dashboard of a car can suddenly seem to accelerate backwards without any force acting on it.

The drink is not accelerating, it's standing still. The reference frame, the car, is accelerating underneath it.

Click here for a famous video about frames of reference. watch the first 2:30 of the video

Newton's 2nd Law of Motion

Demo

Lab

https://www.njctl.org/video/?v=P992ewdTsVk

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Newton's Second Law of Motion

An object doesn't change its velocity unless a force acts on it.

How does an object respond to a force when it is applied?

Newton's Second Law of Motion

$$\Sigma F = ma$$

Net Force Mass Acceleration

Newton's second law identifies the relationship between acceleration and force.

When a net force is applied to an object, the object accelerates.

**the word 'net' means overall, or total. We will discuss this in further detail later, but for now just think of ΣF as any force on an object*

Units of Force

$$\Sigma F = ma$$

The unit of force in the SI system is the Newton (N).

Mass is measured in kilograms (kg).

As we know, acceleration is measured in meters/second^2 (m/s^2).

Therefore, the unit of force, the Newton, can be found from the second law

$$\Sigma F = ma$$

$$N = kg*m/s^2$$

7 A 3.5 kg object experiences an acceleration of 0.5 m/s^2. What net force does the object experience?

- A 1.5 N
- B 1.75 N
- C 3.5 N
- D 7 N
- E I need help

Answer

https://www.njctl.org/video/?v=P992ewdTsVk

8 What force is required to accelerate a 1000 kg sports car at 6 m/s^2 ?

- 10 N
- 60 N
- 600 N
- 6000N
- I need help

Answer

https://www.njctl.org/video/?v=k-VzQRkK-Bg

9 A 12 N net force acts on a 36 kg object? How much does it accelerate?

- A 0.33 m/s^2
- B 0.50 m/s^2
- C 1.0 m/s^2
- D 3.0 m/s^2
- E I need help

Answer

https://www.njctl.org/video/?v=zod4zAxpu5M

10 A bat strikes a 0.145 kg baseball with force of 5800 N. What acceleration does the baseball experience?

A $10\ m/s^2$

B $5800\ m/s^2$

C $10000\ m/s^2$

D $40000\ m/s^2$

E I need help

https://www.njctl.org/video/?v=43e7Ikj9Qj8

Answer

11 An electric model train is accelerated at a rate of 8 m/s^2 by a 12 N force? What is the mass of the train?

- A 1.5 kg
- B 3 kg
- C 4.5 kg
- D 9 kg
- E I need help

Answer

https://www.njctl.org/video/?v=YFwVyf4--Vs

12 An Olympic sprinter accelerates at a rate of 3 m/s^2 by applying a force of 189 N. What is the runner's mass?

- A 18 kg
- B 35 kg
- C 63 kg
- D 126 kg
- E I need help

Answer

https://www.njctl.org/video/?v=HIVbig8cw0U

13 How much net force is required to accelerate a 0.5 kg toy car, initially at rest to a velocity of 2.4 m/s in 6 s?

- A 0.1 N
- B 0.2 N
- C 1.2 N
- D 2.4 N
- E I need help

Answer

https://www.njctl.org/video/?v=tfZh-LoR1QU

Newton's Second Law of Motion

$$\Sigma F = ma$$

We can rearrange this equation to better see how force, mass, and acceleration are related.

$$a = \frac{\Sigma F}{m}$$

https://www.njctl.org/video/?v=bxlq6kGNf80

Newton's Second Law of Motion

$$a = \frac{\Sigma F}{m}$$

The acceleration of an object is:

· Directly proportional to (or dependent upon) the net force acting upon the object. As the force acting upon an object is increased, the acceleration of the object is increased.

· Inversely proportional to the mass of the object. As the mass of an object is increased, the acceleration of the object is decreased!

14 A net force F accelerates a mass m with an acceleration a. If the same net force is applied to mass 2m, then the acceleration will be

- A 4a
- B 2a
- C a/2
- D a/4
- E I need help

Answer

https://www.njctl.org/video/?v=bxlq6kGNf80

15 A net force F accelerates a mass m with an acceleration a. If the same net force is applied to mass m/2, then the acceleration will be

- A 4a
- B 2a
- C a/2
- D a/4
- E I need help

Answer

https://www.njctl.org/video/?v=2GNfXwkKBJk

16 A constant net force acts on an object. The object moves with:

- A constant acceleration
- B constant speed
- C constant velocity
- D increasing acceleration
- E I need help

Answer

https://www.njctl.org/video/?v=y_p-fnsUrcU

17 A net force F acts on a mass m and produces an acceleration a. What acceleration results if a net force 2F acts on mass 4m?

- A a/2
- B 8a
- C 4a
- D 2a
- E I need help

Answer

https://www.njctl.org/video/?v=xfTQMqug9Tg

18 The acceleration of an object is inversely proportional to:

- A the net force acting on it.
- B its position.
- C its velocity.
- D its mass.
- E I need help

Answer

https://www.njctl.org/video/?v=j5FmGL8cmw8

Net Force
ΣF

https://www.njctl.org/video/?v=zSwhCKWnTlg

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Net Force

$$\Sigma\bar{F} = m\bar{a}$$

Let's look at the left side of this equation first.

$$\Sigma\bar{F}$$

The greek letter sigma "Σ" means "the sum of".

Sometimes ΣF is written as F_{Net} or net Force.

ΣF and F_{Net} both mean you add up all the forces acting on an object.

Net Force

$$\Sigma \vec{F}$$

The arrow above "F" reminds you that force is a vector. We won't always write the arrow but remember it's there.

It means that when you add forces, you have to add them like vectors: forces have direction, and they can cancel out.

Net Force

$$\Sigma \overline{F}$$

Example: A 5.0 kg object is being acted on by a 20N force to the right (F_1), and a 30N force, also to the right (F_2). What is the net force on the object?

First we'll draw a free body diagram. We will discuss these in more detail later on but for now, follow these simple directions. FBDs consists of a dot, representing the object, and arrows representing the forces. The direction of the arrows represents the direction of the forces...their length is roughly proportional to their size.

Newton's Second Law of Motion

$$\Sigma \overline{F}$$

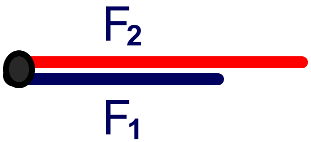
Example: A 5.0 kg object is being acted on by a 20N force to the right (F_1), and a 30N force, also to the right (F_2). What is the net force on the object?

The first force (F_1) acts to the right with a magnitude of 20 N

Newton's Second Law of Motion

$$\Sigma \overline{F}$$

Example: A 5.0 kg object is being acted on by a 20N force to the right (F_1), and a 30N force, also to the right (F_2). What is the net force on the object?



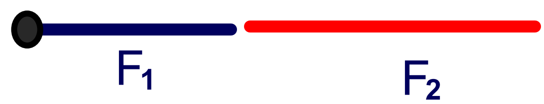
The second force, F_2, acts to the right also, with a greater magnitude of 30N. This is drawn slightly larger than F_1.

Newton's Second Law of Motion

$$\Sigma \overline{F}$$

Example: A 5.0 kg object is being acted on by a 20N force to the right (F_1), and a 30N force, also to the right (F_2). What is the net force on the object?

To add vectors, move the second vector so it starts where the first one ends.

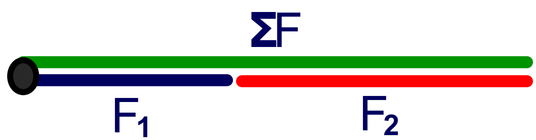


The sum is a vector which starts where the first vector started, and ends where the last one ends.

Newton's Second Law of Motion

$$\Sigma \overline{F}$$

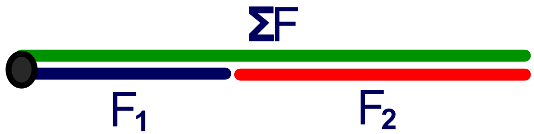
Example: A 5.0 kg object is being acted on by a 20N force to the right (F_1), and a 30N force, also to the right (F_2). What is the net force on the object?



These free body diagrams are critically important to our work. Once done, the problem can be translated into an algebra problem.

Newton's Second Law of Motion

For example: A 5.0 kg object is being acted on by a 20N force to the right (F_1), and a 30N force, also to the right (F_2). What is the net force on the object?



First we will define "to the right" as positive.

Then we can interpret our diagram to read:

$\Sigma F = F_1 + F_2$

$\Sigma F = 20\text{ N} + 30\text{ N}$

$\Sigma F = 50\text{N}$ to the right

(we get the direction from our diagram and from our positive answer, which we defined as meaning "to the right")

19 Two forces act on an object. One force is 40N to the west and the other force is 40N to the east. What is the net force acting on the object?

- A 0 N
- B 40 N East
- C 80 N East
- D 80 N West
- E I need help

Answer

https://www.njctl.org/video/?v=zSwhCKWnTlg

20 Two forces act on an object. One force is 8.0N to the north and the other force is 6.0N to the south. What is the net force acting on the object?

- A 0 N
- B 2 N North
- C 2 N South
- D 14 N North
- E I need help

Answer

https://www.njctl.org/video/?v=oqZMClMWF-o

Newton’s Second Law of Motion

$$m\bar{a}$$

Now let's look at the right side of our equation, $m\bar{a}$.

Mass is a scalar...it does not have a direction.

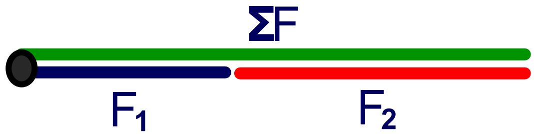
But acceleration does have a direction...it is a vector.

The direction of the acceleration vector is always the same as the direction of the net force, ΣF, vector.

https://www.njctl.org/video/?v=yL3g2HaI5Hg

Newton’s Second Law of Motion

For example: A 5.0 kg object is being acted on by a 20N force to the right (F_1), and a 30N force, also to the right (F_2). We found the net force on the object to be 50N to the right.

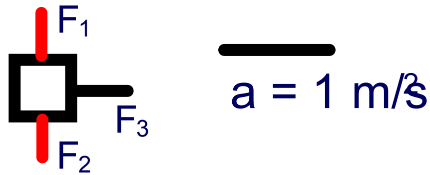


Now let's find its acceleration.

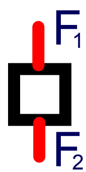
Answer

Newton's Second Law of Motion

What is the net Force acting on the object below?
Force is a vector, so $\Sigma F = ma$ is true along each coordinate axis.



That means we can add up all the forces in the vertical direction and those will equal "ma" in the vertical direction.

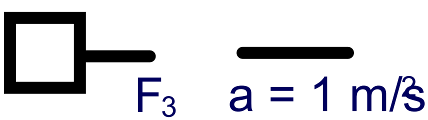


$F_1 + (-F_2) = m\cancel{a}$ (vertical)

0

$F_1 - F_2 = 0$

And then can do the same thing in the horizontal direction.



$F_3 = ma$

$F_3 = (2kg)(1\ m/s^2)$

$F_3 = 2\ N$

21 A force F_1 = 50N acts to the right on a 5 kg object.

Another force on the object, F_2 = 30N, acts to the left. Find the acceleration of the object.

- A -4 m/s^2
- B 0 m/s^2
- C +4 m/s^2
- D +16 m/s^2
- E I need help

https://www.njctl.org/video/?v=R372S8_gkfg

Answer

22 A force F_1 = 350N pushes upward on 20 kg object. Another force, F_2 = 450N pulls downward on the object. Find the acceleration of the object.

- A $-40\ m/s^2$
- B $-5\ m/s^2$
- C $5\ m/s^2$
- D $40\ m/s^2$
- E I need help

https://www.njctl.org/video/?v=eH2mgUqhwi8

Answer

23 An object accelerates downward at a rate of 4.9 m/s^2. If the downward force on the object is 500N and the upward force is 250N, what is the mass of the object?

- A 0 kg
- B 51 kg
- C 102 kg
- D 150 kg
- E I need help

https://www.njctl.org/video/?v=07JMzvwaM2E

Answer

Mass, Weight, and Normal Force

https://www.njctl.org/video/?v=EiJv-rDFswA

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The case of mass versus weight

Mass is the measure of the inertia of an object, the resistance of an object to accelerate. In the SI system, mass is measured in kilograms.

Mass is not weight !
Mass is a property of an object.
It doesn't depend on where the object is located.

Weight is the force exerted on that object by gravity.
If you go to the moon, whose gravitational acceleration is about 1/6 g, you will weigh much less. Your mass, however, will be the same.

Click on this link to see a *Veritasium* video about mass and weight!

Weight – the Force of Gravity

Weight is the force exerted on an object by gravity. Close to the surface of Earth, where the gravitational force is nearly constant, weight can be calculated with:

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

or

$$W = mg$$

Near the surface of Earth, g is 9.8 m/s^2 *downwards*.

24 Determine the Force of Gravity (weight)on a 6.0 kg bowling ball.

- A 0 N
- B 0.61 N
- C 59 N
- D 180 N
- E I need help

Answer

https://www.njctl.org/video/?v=EiJv-rDFswA

25 Determine the weight of a small car with a mass of 900.0 kg.

- A 90.00 N
- B 180.0 N
- C 1800 N
- D 8820 N
- E I need help

Answer

https://www.njctl.org/video/?v=90QebbPtyAA

26 Using a spring scale, you find that the weight of a friction block in the lab is 24 N. What is the mass of the block in kilograms?

- A 2.5 N
- B 4.9 N
- C 24 N
- D 240 N
- E I need help

https://www.njctl.org/video/?v=qnu5gNseagY

Answer

27 An object located near the surface of Earth has a weight of a 245 N. What is the mass of the object?

- A 25 kg
- B 90 kg
- C 150 kg
- D 2400 kg
- E I need help

Answer

https://www.njctl.org/video/?v=rP83F6Cc-dA

28 Which of the following properties of an object is likely to change on another planet?

- A Mass
- B Weight
- C Color
- D Volume (size and shape)
- E I need help

Answer

https://www.njctl.org/video/?v=vTR_E6QTkGM

29 The acceleration due to gravity is lower on the Moon than on Earth. Which of the following is true about the mass and weight of an astronaut on the Moon's surface, compared to Earth?

- A Mass is less, weight is same
- B Mass is same, weight is less
- C Both mass and weight are less
- D Both mass and weight are the same
- E I need help

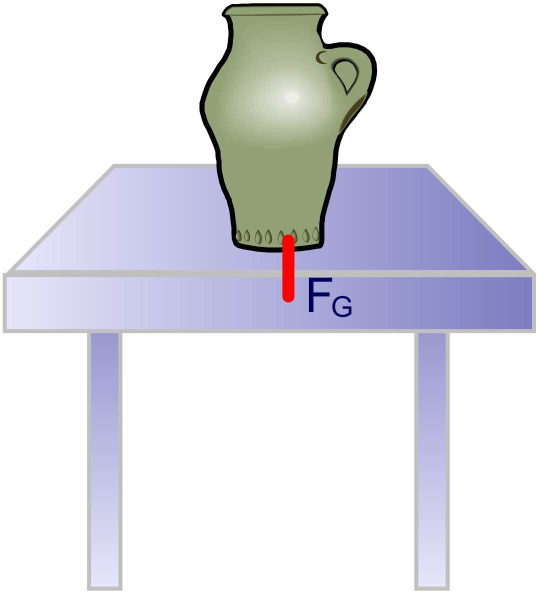
Answer

https://www.njctl.org/video/?v=8HpLY1vQKrA

Weight – the Force of Gravity

An object at rest must have no net force on it.

If it is sitting on a table, the force of gravity is still there...

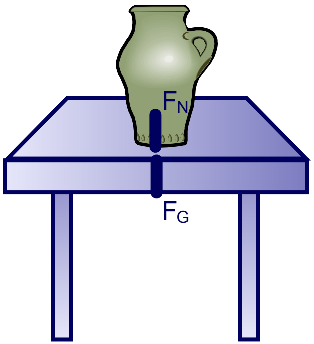


but additionally, *what other force is there?*

https://www.njctl.org/video/?v=-rMNsjZF0g8

The Normal Force

What is the other force?



The force exerted perpendicular to a surface is called the normal force.

The normal force is exactly as large as needed to balance the force from the object. (if the required force gets too big, something breaks!)

The words "normal" and "perpendicular" are synonyms.

30 A 14 N brick is sitting on a table. What is the normal force supplied by the table?

- A 14 N upwards
- B 28 N upwards
- C 14 N downwards
- D 28 N downwards
- E I need help

Answer

https://www.njctl.org/video/?v=hnu4FsDE3IQ

31 What normal force is supplied by adesk to a 2.00 kg box sitting on it?

- A 0 N
- B 9.80 N
- C 19.6 N
- D 39.2 N
- E I need help

https://www.njctl.org/video/?v=p4UCHVTKyJg

Answer

Newton's 3rd Law of Motion

Demo

https://www.njctl.org/video/?v=soU1VmbNlo8

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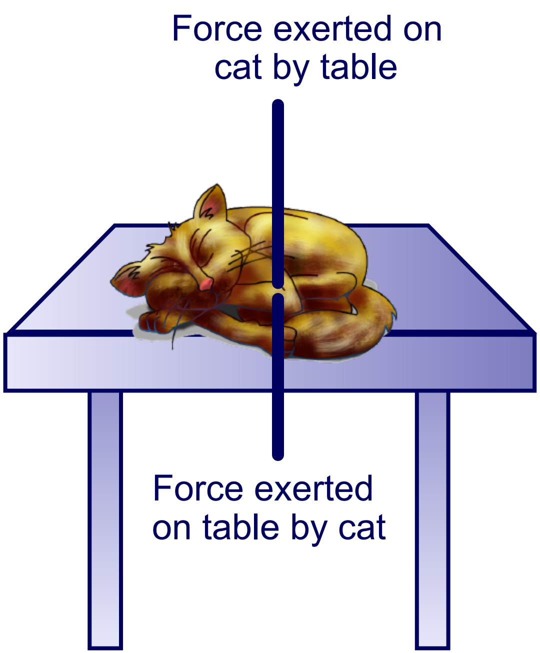
Newton’s Third Law of Motion

Any time a force is exerted on an object, that force is caused by another object.

There must be two objects involved to have a force

Newton’s third law :

Whenever one object exerts a force on a second object, the second object exerts an equal force in the opposite direction on the first object.



Newton's Third Law of Motion

Whenever one object exerts a force on a second object, the second object exerts an equal force in the opposite direction on the first object.

Another way to state Newton's 3rd Law...

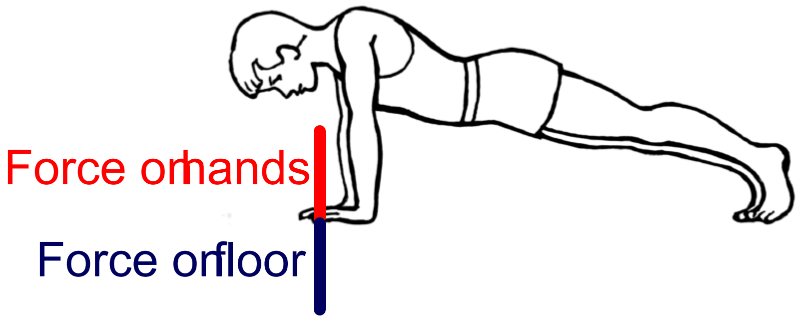
For every action, there is an equal, opposite reaction .

Remember: forces (or actions) are always applied to two different objects.

Newton's Third Law of Motion

A key to the correct application of the third law is that *the forces are exerted on different objects*.

Make sure you don't use them as if they were acting on the *same* object. Then they would add to zero!



Newton’s Third Law of Motion

Rocket propulsion can also be explained using Newton’s third law.

Hot gases from combustion spew out of the tail of the rocket at high speeds. The reaction force is what propels the rocket.

Note that the rocketdoes not need anything (like the earth) to “push” against.

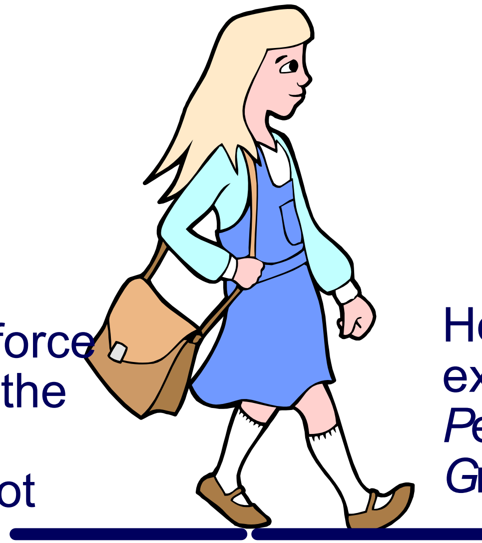
Newton’s Third Law of Motion

Subscripts help keep your ideas and equations clear.

- the first subscript is the object that the force is being exerted on;
- the second is the source of that force.

$$F_{GP} = -F_{PG}$$

$$\overline{F}_{GP} = \overline{F}_{PG}$$



Horizontal force exerted on the *G*round by *P*erson's foot

Horizontal force exerted on the *P*erson's foot by *G*round

F_{GP} F_{PG}

32 An object of mass m sits on a flat table. The Earth pulls on this object with force mg, which we will call the action force. What is the reaction force?

- A The table pushing up on the object with force mg
- B The object pushing down on the table with force mg
- C The table pushing down on the floor with force mg
- D The object pulling upward on the Earth with force mg
- E I need help

https://www.njctl.org/video/?v=65Oh_b-04Kw

Answer

33 A 20-ton truck collides with a 1500-lb car and causes a lot of damage to the car. Since a lot of damage is done on the car:

A the force on the truck is greater then the force on the car

B the force on the truck is equal to the force on the car

C the force on the truck is smaller than the force on the car

D the truck did not slow down during the collision

E I need help

Answer

https://www.njctl.org/video/?v=TxNl943lE-g

34 As you are sitting in a chair, you feel the chair pushing up on you. The reaction force in this situation is:

- A The chair pushing down on the ground
- B Gravity pulling down on you
- C You pushing down on the chair
- D The ground pushing up on the chair
- E I need help

Answer

https://www.njctl.org/video/?v=_ft1IKa5xno

35 A student is doing a hand-stand. A reaction pair of forces is best described as:

- A The student pushes down on the ground - The ground pushes up on the student
- B Gravity is pulling the student down - The ground is pushing the student up
- C Gravity is pulling the student down - The student's arms push the student up
- D The student's hands push down on the ground - The students arms push the student up
- E I need help

https://www.njctl.org/video/?v=F-OJLUCBZVs

Answer

36 Which of Newton's laws best explains why motorists should wear seat belts?

- A the first law
- B the second law
- C the third law
- D the law of gravitation
- E I need help

Answer

https://www.njctl.org/video/?v=3sCSIbgmvVE

37 If you blow up a balloon, and then release it, the balloon will fly away. This is an illustration of:
(Note: there may be more than one answer. Be prepared to explain WHY!)

- A Newton's first law
- B Newton's second law
- C Newton's third law
- D Galileo's law of inertia
- E I need help

Answer

https://www.njctl.org/video/?v=ox9QqJBS0C0

Free Body Diagrams

https://www.njctl.org/video/?v=VQNJWvfV4bk

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Free Body Diagrams

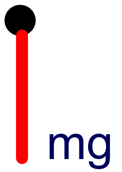
A free body diagram is a drawing physicists use in order to show all the forces acting on an object. Drawing free body diagrams can help when trying to solve for unknown forces or showing the motion of the object.

Click here for a *Veritasium* video on free body diagrams and reviewing Normal Force!

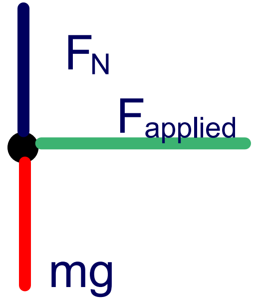
Free Body Diagrams

1. Draw and label a dot to represent the first object.

2. Draw an arrow from the dot pointing in the direction of one of the forces that is acting on that object. Label that arrow with the name of the force.



3. Repeat for every force that is acting on the object. Try to draw each of the arrows to roughly the same scale, bigger forces getting bigger arrows.

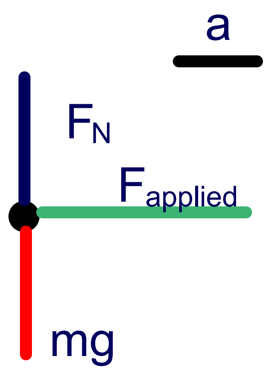


Free Body Diagrams

4. Once you have finished your free body diagram, recheck it to make sure that you have drawn and labeled an arrow for every force. This is no time to forget a force.

5. Draw a separate arrow next to your free body diagram indicating the likely direction of the acceleration of the object. This will help you use your free body diagram effectively.

6. Repeat this process for every object in your sketch.



38 Draw the free body diagram for a cat sitting on a chair.

Answer

https://www.njctl.org/video/?v=VQNJWvfV4bk

39 Draw the free diagram for a sled being pulled across an icy pond.

Answer

https://www.njctl.org/video/?v=4KSUlnWKHps

Friction

Demo

Lab

https://www.njctl.org/video/?v=6qMm8-y2DJU

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Friction - A Resistive Force

There are many different types of forces that occur in nature, but perhaps none is more familiar to us than the force of friction (F_{fr}).

Friction is a resistive force that opposes the motion of an object.

What does sandpaper have to do with friction?

Friction - A Resistive Force

Friction is the reason objects stop rolling or sliding along a surface. It is the reason it is difficult to start pushing a heavy box along the floor.

There are many different types of friction:

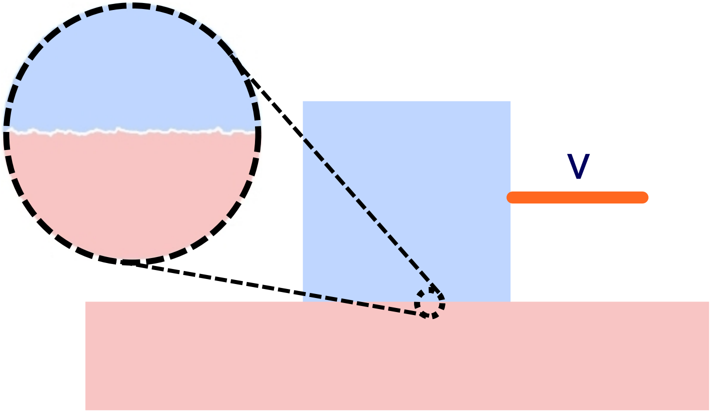
Friction between solid objects and air is often called air resistance.

Friction between two fluids is called viscosity.

Kinetic Friction Force

Where does friction come from?

On a microscopic scale, most surfaces are rough. This leads to complex interactions between them that we don't need to consider yet, but the force can be modeled in a simple way.



Kinetic Friction Force

Friction that acts on an object that is already in motion is called kinetic friction.

For kinetic – or sliding – friction, we write: $\mathbf{F_{fr} = \mu_k F_N}$

Kinetic friction is the product of two things: μ_k is called the coefficient of kinetic friction, and is different for every pair of surfaces. F_N is simply the Normal Force, which, on flat surfaces, is equal to the weight of the object.

Kinetic Friction Force

A larger coefficient of friction means a greater frictional force.

Notice the friction that occurs between different materials in the table below:

Surface	**Coefficient of Kinetic Friction**
Wood on Wood	0.2
Ice on Ice	0.03
metal on metal (lubricated)	0.07
Steel on steel (unlubricated)	0.6
Rubber on dry concrete	0.7
Rubber on wet concrete	0.6
Rubber on other solid surface	0.5 - 0.9
Teflon on Teflon	0.05
Human Joints in limbs	0.01

Kinetic Friction Force

A man accelerates a crate along a rough surface.

Draw the crate's free body diagram:

move for answer

Determine ΣF in the x and y directions

move for answer

move for answer

40 A brick is sliding to the right on a horizontal surface. What are the directions of the two surface forces: the friction force and the normal force?

- A right, down
- B right, up
- C left, down
- D left, up
- E I need help

Answer

https://www.njctl.org/video/?v=HDqDH1Rkx9Q

41 A 4.0kg brick is sliding on a surface. The coefficient of kinetic friction between the surfaces is 0.25. What it the size of the force of friction?

- A 0 N
- B 4.9 N
- C 9.8 N
- D 19.6 N
- E I need help

https://www.njctl.org/video/?v=-_im4E6iCcA

Answer

42 A 50 kg crate is being pushed across a warehouse floor. The coefficient of kinetic friction between the crate and the floor is 0.4. What is the size of the force of friction?

- A 0 N
- B 200 N
- C 500 N
- D 1300 N
- E I need help

https://www.njctl.org/video/?v=6A_FxFj2I0M

Answer

43 A 50 kg crate is pushed across a warehouse floor with a force of 100 N, accelerating at a rate of 1 m/s^2. What is the coefficient of friction between the floor and crate?

- A 0.1
- B 0.2
- C 0.5
- D 0.8
- E I need help

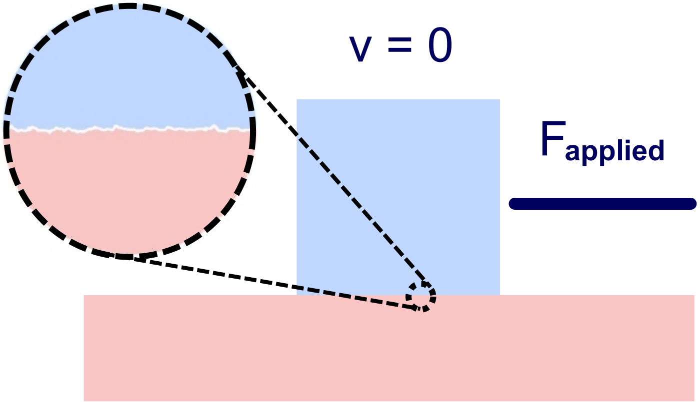
https://www.njctl.org/video/?v=euLjmMhCArI

Answer

**Static Friction Force

Static friction is the frictional force between two surfaces that are not moving along each other.

Static friction keeps objects from moving when a force is first applied.



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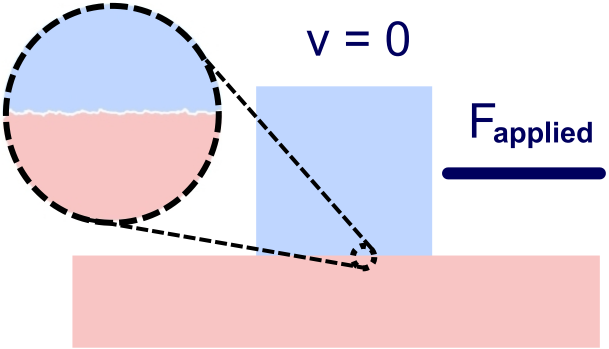
**Static Friction Force

$$F_{fr} \leq \mu_s F_N$$

μ_s is the coefficient of static friction, and is different for every pair of surfaces.



** Static Friction Force

$$F_{fr} \leq \mu_s F_N$$

Note the ≤ symbol in this equation.

Imagine pushing on a box until it moves. You can apply a small force... nothing happens. You apply more and more force until the box finally starts moving - this is the maximum amount of static friction.

The friction can be LESS than the maximum amount or EQUAL to the maximum amount, but never greater. The force of friction is equal to $\mu_s F_N$ at the instant when the object starts to move.

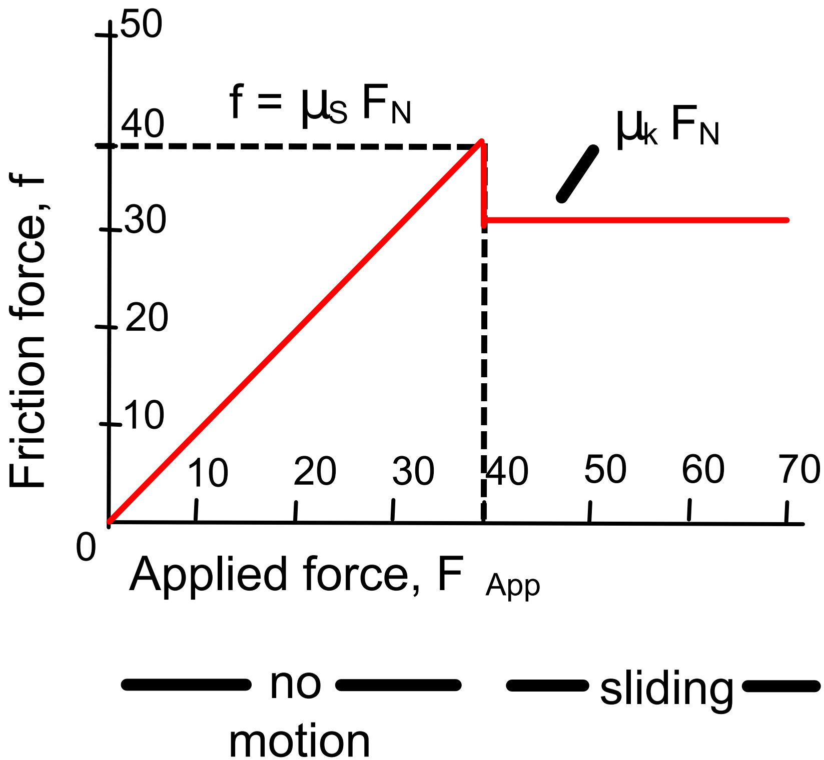
Then what happens?

** Friction Force

The static frictional force increases as the applied force increases, always equal to the net applied force.

Until it reaches its maximum, $\mu_s F_N$.

Then the object starts to move, and the kinetic frictional force takes over, $\mu_K F_N$.



** Friction Force

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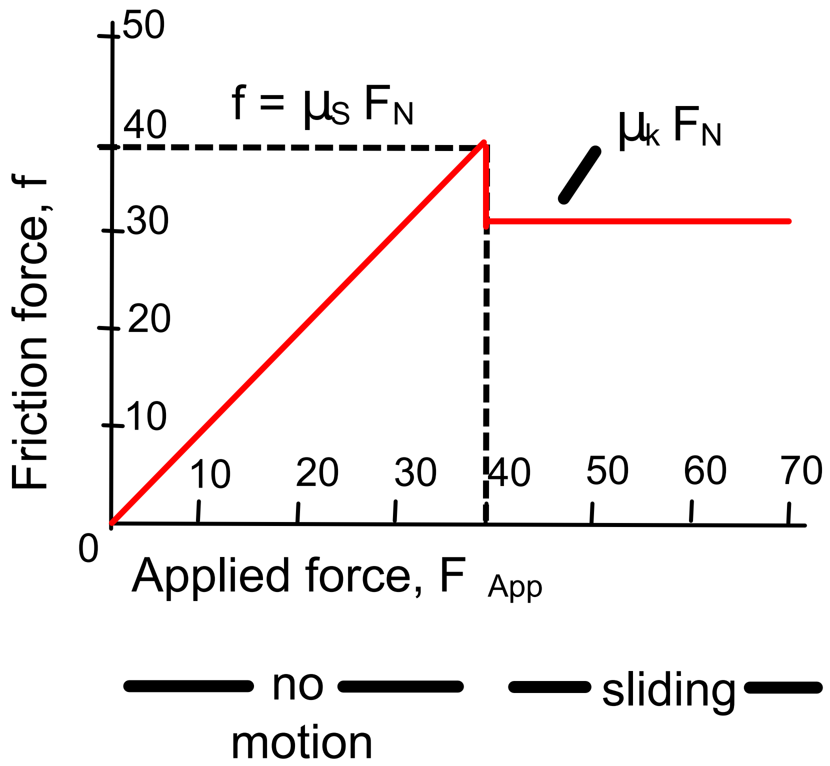

**Friction Force

The table below shows values for both static and kinetic coefficients of friction.

Surface	Coefficient of Static Friction	Coefficient of Kinetic Friction
Wood on wood	0.4	0.2
Ice on ice	0.1	0.03
Metal on metal(lubricated)	0.15	0.07
Steel on steel (unlubricated)	0.7	0.6
Rubber on dry concrete	1.0	0.8
Rubber on wet concrete	0.7	0.5
Rubber on other solid surfaces	1-4	1
Teflon on Teflon in air	0.04	0.04
Joints in human limbs	0.01	0.01

Notice that static friction is greater than kinetic friction. Once an object is in motion, it is easier to keep it in motion.

**44 A 4.0 kg brick is sitting on a table. The coefficient of static friction between the surfaces is 0.45. What is the largest force that can be applied horizontally to the brick before it begins to slide?

A 4.5 N

B 6.1 N

C 18N

D 34 N

E I need help

Answer

https://www.njctl.org/video/?v=C336w6F3MTU

**45 A 4.0kg brick is sitting on a table. The coefficient of static friction between the surfaces is 0.45. If a 10 N horizontal force is applied to the brick, what will be the force of friction?

- A 0 N
- B 8 N
- C 10 N
- D 18 N
- E I need help

https://www.njctl.org/video/?v=XPztoTbZfcc

Answer

Tension

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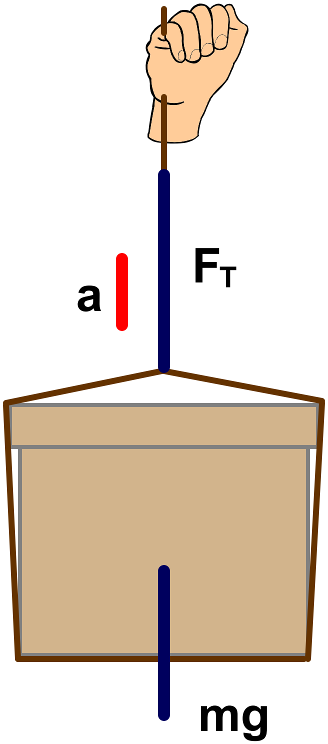
Tension Force

When a cord, rope or chain pulls on an object, it is said to be under tension, and the force it exerts is called a tension force, F_T.

The tension force is the same throughout the cord, rope or chain (when assumed to be massless).

Any object that is hanging or suspended is considered to have tension acting upward.

Any object that is pulled is considered to have tension acting on it.



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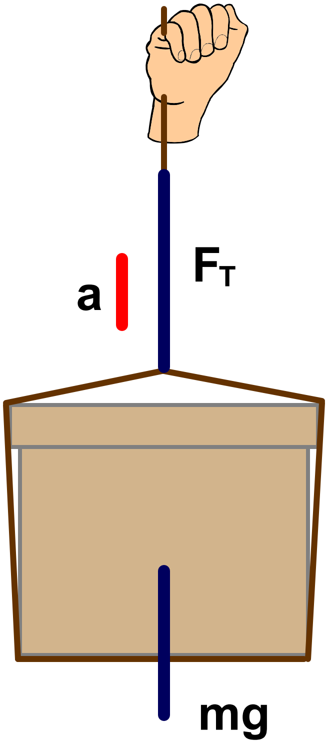
Tension Force

There is no special formula to find the force of tension.

We need to use force diagrams and net force equations to solve for it!



46 A 25 kg lamp is hanging from a rope. What is the tension force being supplied by the rope?

- A 0 N
- B 25 N
- C 250 N
- D 490 N
- E I need help

Answer

https://www.njctl.org/video/?v=MVU9IvK873A

47 A crane is lifting a 60 kg load at a constant velocity. Determine the tension force in the cable.

- A 0 N
- B 59 N
- C 290 N
- D 590 N
- E I need help

https://www.njctl.org/video/?v=P-Unghz4hzY

Answer

48 A 90 kg climber rappels from the top of a cliff with an acceleration of 1.0 m/s². Determine the tension in the climber's rope.

- A 0 N
- B 790 N
- C 920 N
- D 970 N
- E I need help

https://www.njctl.org/video/?v=gKd2li9p0lc

Answer

49 A crane lifts a 400 kg crate upward with an acceleration of 3.00 m/s². Determine the tension in the crane.

- 0 N
- 2800 N
- 3920 N
- 5120 N
- I need help

Answer

https://www.njctl.org/video/?v=SkLcaVFt6Wc

General Problems

Lab

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Problem Solving – A General Approach

- Read the problem carefully; then read it again.
- Draw a sketch, and then a free-body diagram.
- Choose a convenient coordinate system.
- List the known and unknown quantities;
- Find relationships between the knowns and unknowns.
- Estimate the answer.
- Solve the problem without numbers, algebraically.
- Then put the numbers in and solve for a numerical answer.
- Keep track of dimensions.
- Make sure your answer is reasonable.

Defining the Object of Interest

Newton's Laws can be applied to all objects.

If there are two connected objects in a problem, you can use Newton's Laws to solve for each of the separate object.

And/or you can solve for the combination of objects.

You will get the same answers.

But, choosing the object to work with carefully could lead to a quicker, easier path to the solution

Problem 1

An 1800 kg elevator moves up and down on a cable. Calculate the tension force in the cable for the following cases:

a) the elevator moves at a constant speed upward.
b) the elevator moves at a constant speed downward.
c) the elevator accelerates upward at a rate of 2.4 m/s^2.
d) the elevator accelerates downward at a rate of 2.4 m/s^2.

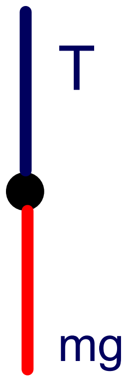
Problem 1

An 1800 kg elevator moves up and down on a cable. Calculate the tension force in the cable for the following cases:

a) the elevator moves at a constant speed upward.

The words, "moves at a constant speed upwards" means that the acceleration equals zero.

First, draw a free body diagram showing all forces and the direction of acceleration.



a=0

Problem 1

An 1800 kg elevator moves up and down on a cable. Calculate the tension force in the cable if:

a) the elevator moves at a constant speed upward.

Then use the second law to solve for T.

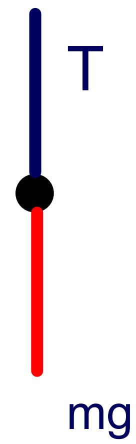
If a=0, then $\Sigma F=0$

$\Sigma F = T - mg = 0$

$T = mg$

$T = (1800kg)(9.8\ m/s^2)$

$T = 17{,}640\ N$



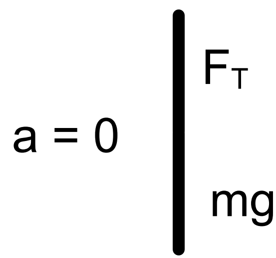
a=0

Problem 1

An 1800 kg elevator moves up and down on a cable. Calculate the tension force in the cable for the following cases:

b) the elevator moves at a constant speed downward.

Given:
$m = 1800$ kg
$g = 9.8$ m/s^2
$a = 0$ (constant speed)
$F_T = ?$



$\Sigma F = ma$

$F_T - mg = ma$ *and a =0,*

No different than if the constant speed is upward!

$F_T - mg = 0$

$F_T = mg$

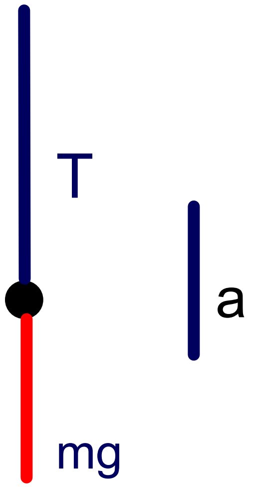
$F_T = (1800 \text{ kg})(9.8 \text{ m/s}^2)$
$F_T = 17{,}640$ N

Problem 1

An 1800 kg elevator moves up and down on a cable. Calculate the tension force in the cable for the following cases:

c) the elevator accelerates upward at a rate of 2.4 m/s^2.

First, draw a free body diagram showing all forces and acceleration.



Problem 1

An 1800 kg elevator moves up and down on a cable. Calculate the tension force in the cable for the following cases:

c) the elevator accelerates upward at a rate of 2.4 m/s^2.

Then use the second law to solve for T.

$\Sigma F = ma$

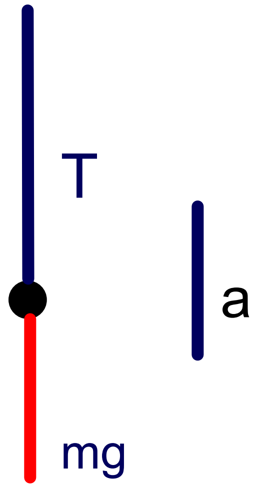
$T - mg = ma$

$T = mg + ma$

$T = m(g+a)$

$T = (1800kg)(9.8\ m/s^2 + 2.4\ m/s^2)$

$T = 22{,}000\ N$

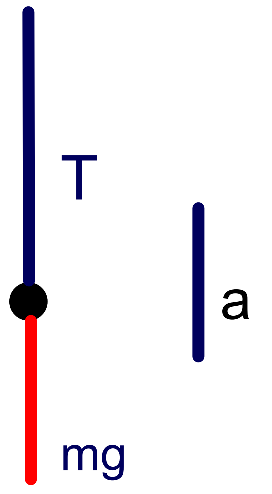


Problem 1

An 1800 kg elevator moves up and down on a cable. Calculate the tension force in the cable for the following cases:

d) the elevator accelerates downward at a rate of 2.4 m/s^2.

First, draw a free body diagram showing all forces and acceleration.



Problem 1

An 1800 kg elevator moves up and down on a cable. Calculate the tension force in the cable for the following cases:

d) the elevator accelerates downward at a rate of 2.4 m/s^2.

Then use the second law to solve for T.

$\Sigma F = ma$

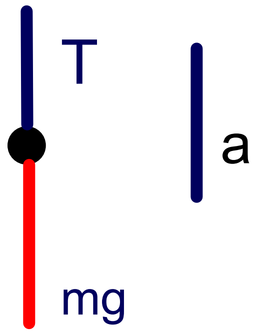
$T - mg = ma$

$T = mg + ma$

$T = m(g - a)$

$T = (1800kg)(9.8\ m/s^2 - 2.4\ m/s^2)$

$T = 13{,}300\ N$



Problem 1

An 1800 kg elevator moves up and down on a cable. Calculate the tension force in the cable for the following cases:

Summary of answers:

Notice that all these answers make sense.

It takes more force to accelerate an object upwards than it does to raise or lower it at constant speed, or just hold it at one height.

And, it takes less force if the object is allowed to accelerate downwards, so the upwards force does not have to support the object's full weight.

Problem 2

A 50 kg man stands on a scale inside an elevator. State the scale measurement for the following cases:

a) the elevator moves at a constant speed upward.
b) the elevator moves at a constant speed downward.
c) the elevator accelerates upward at a rate of 1.4 m/s^2.
d) the elevator accelerates downward at a rate of 1.4 m/s^2.

Problem 2

A 50 kg man stands on a scale inside an elevator. State the scale measurement for the following cases:

a) the elevator moves at a constant speed upward.

Answer

Problem 2

A 50 kg man stands on a scale inside an elevator. State the scale measurement for the following cases:

b) the elevator moves at a constant speed downward.

Answer

Problem 2

A 50 kg man stands on a scale inside an elevator. State the scale measurement for the following cases:

c) the elevator accelerates upward at a rate of 1.4 m/s^2.

Answer

Problem 2

A 50 kg man stands on a scale inside an elevator. State the scale measurement for the following cases:

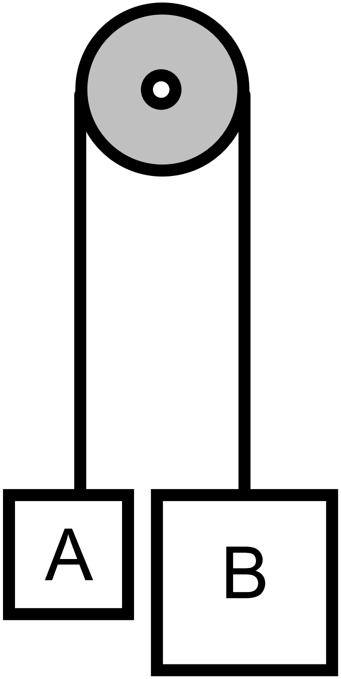
d) the elevator accelerates downward at a rate of 1.4 m/s^2.

Answer

Atwood's Machine

The following problem solves for the dynamics of an Atwood's Machine, which is comprised of two masses connected by an ideal rope passing over a frictionless pulley.

In an ideal rope the tension is the same throughout the rope and directed towards its center and the rope does not stretch.

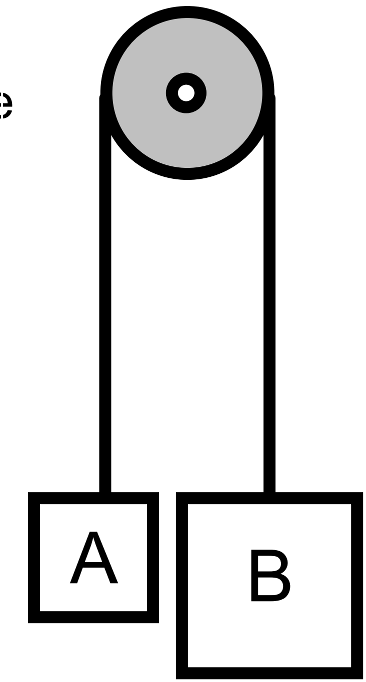


Problem 3

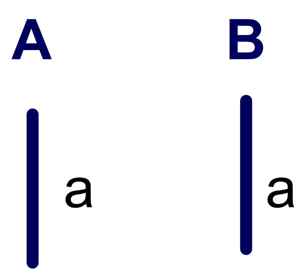
Mass A is 20kg and Mass B is 50 kg.

How will the magnitudes of the accelerations of the block compare with one another?

Which way will each block accelerate?



Their accelerations will be equal and opposite. Can you see why that must be true if the rope cannot stretch?

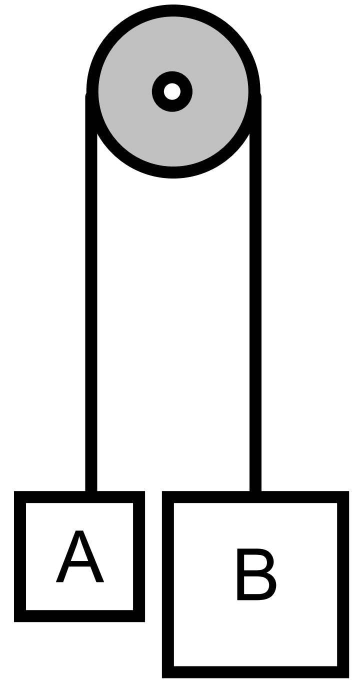


https://www.njctl.org/video/?v=djZCBGVdHwQ

Problem 3

Mass A is 20kg and Mass B is 50 kg.

a) Draw a Free Body Diagram for each mass
b) Write the Net Force equation for each mass
c) Find two equations for the tension force T
d) Find the equation for acceleration
e) Find the value of the acceleration
f) Find the value of the tension force



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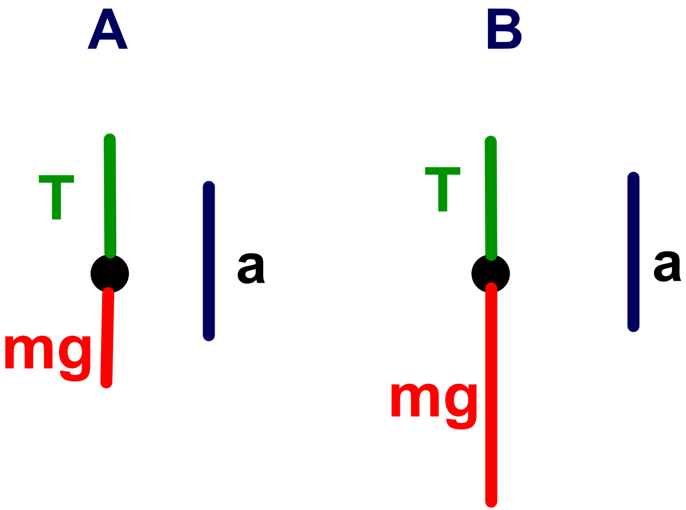
Problem 3

a) Draw a Free Body Diagram for each mass



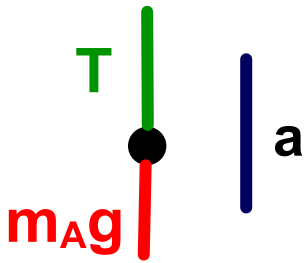
Remember the tension in the rope is the same everywhere, so T is the same for both masses.

Also, since the two masses are connected to each other, they must accelerate at the same rate.

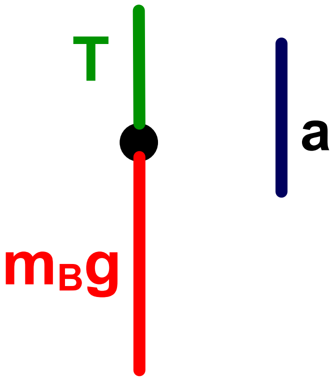
Problem 3

b) Write the Net Force equation for each block.

A



B



$\Sigma F = m_A a$

$T - m_A g = m_A a$

$\Sigma F = -m_B a$

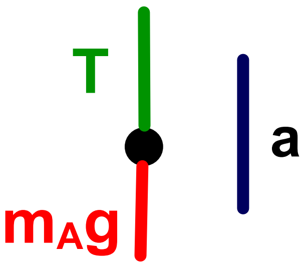
$T - m_B g = -m_B a$

Answer

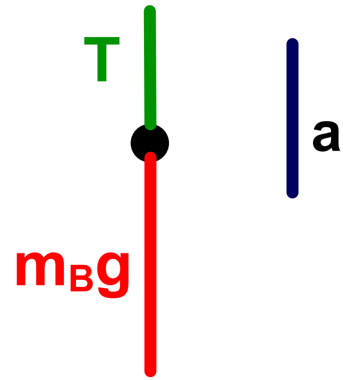
Problem 3

c) Find two equations for the tension force T

A



B



$\Sigma F = m_A a$

$T - m_A g = m_A a$

$T = m_A g + m_A a$

$\Sigma F = -m_B a$

$T - m_B g = -m_B a$

$T = m_B g - m_B a$

Problem 3

d) Find the equation for acceleration.

We have two independent equations for T.

Set them equal to one another (T=T) and then solve for a.

$T = m_B g - m_B a$

$T = m_A g + m_A a$

$T = T$

$m_A g + m_A a = m_B g - m_B a$

$m_A a + m_B a = m_B g - m_A g$

$a(m_A + m_B) = g(m_B - m_A)$

$$a = g\frac{(m_B - m_A)}{(m_A + m_B)}$$

Problem 3

d) Find the equation for acceleration.

We have two independent equations for T.

Set them equal to one another (T=T) and then solve for a.

$$T = m_B g - m_B a$$

$$T = m_A g + m_A a$$

$$T = T$$

$$m_A g + m_A a = m_B g - m_B a$$

$$m_A a + m_B a = m_B g - m_A g$$

$$a(m_A + m_B) = g(m_B - m_A)$$

$$a = g\frac{(m_B - m_A)}{(m_A + m_B)}$$

Problem 3

e) Find the value of the acceleration

$$a = g\,\frac{(m_B - m_A)}{(m_A + m_B)}$$

$$a = g\,\frac{(50kg - 20kg)}{(50kg + 20kg)}$$

$$a = g\,\frac{30}{70}$$

$$a = 3/7\ g$$

$$a = 4.2\ m/s^2$$

Problem 3

f) Find the value of the tension force

Plug the value of acceleration into either of the equations we developed for T. Use the second equation to check all our work. If we get the same answers, we can be sure we're right.

$T = m_A g + m_A a$

$T = m_A(g + a)$

$T = 20kg\ (9.8 + 4.2)m/s^2$

$T = 20k\ (14m/s^2)$

$T = 280N$

$T = m_B g - m_B a$

$T = m_B(g - a)$

$T = 50kg\ (9.8 - 4.2)m/s^2$

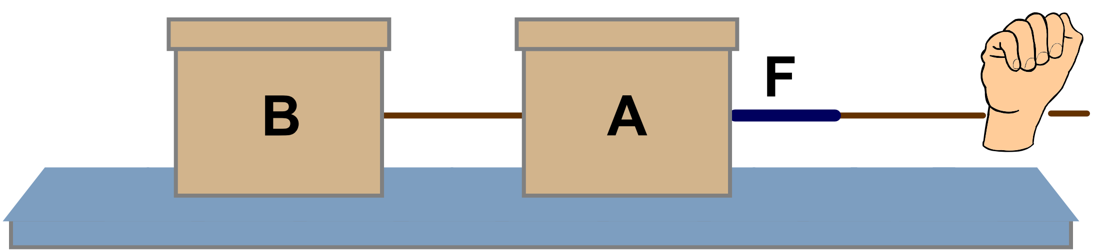
$T = 50kg\ (5.6)m/s^2$

$T = 280N$

Problem 4

Two boxes, connected by a cord, are pulled horizontally with a force of 40.0 N, as shown below. Box A has a mass of 10 kg; Box B has a mass of 12 kg. Ignore friction.

a) Show the free-body diagram of the box B.
b) Show the free-body diagram of the box A.
c) Show the free-body diagram for the combination of boxes A and B.
c) Find the acceleration of the system.
d) Find the tension in the cord.



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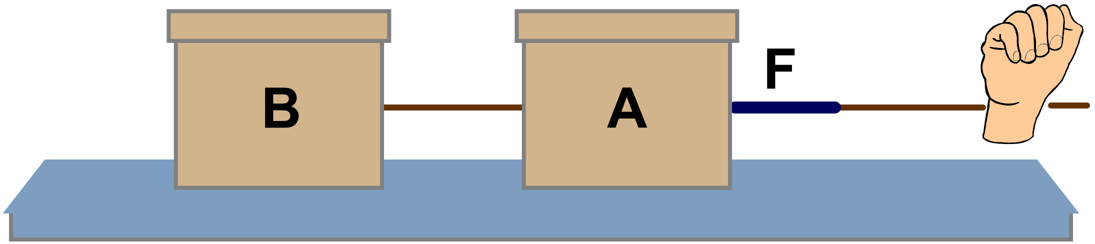
Problem 4

F = 40N; M_A = 10kg; M_B = 12kg

a) Show the free-body diagram of the box B.

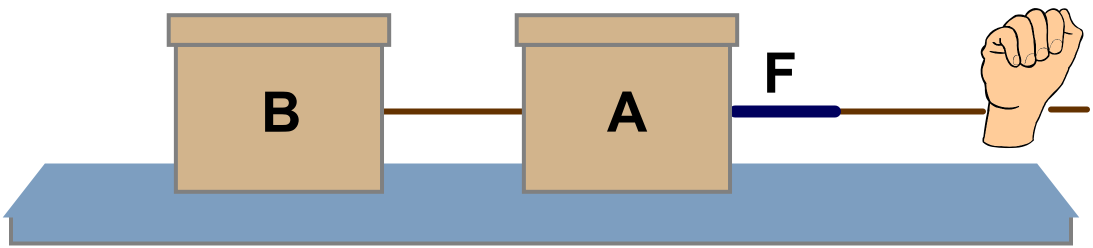


Answer

Problem 4

F = 40N; M_A = 10kg; M_B = 12kg

b) Show the free-body diagram of the box A.

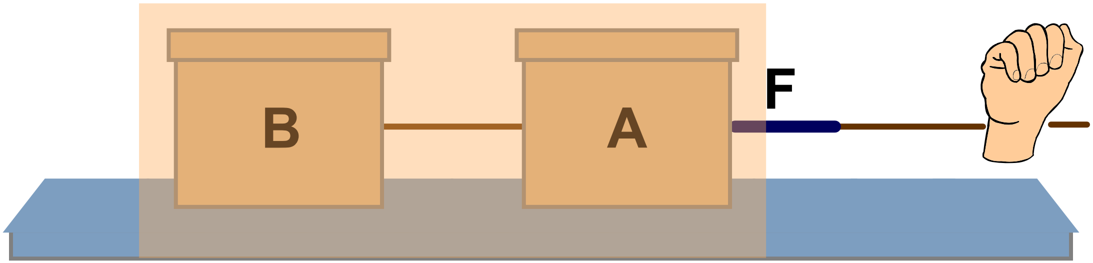


Answer

Problem 4

F = 40N; M_A = 10kg; M_B = 12kg

c) Show the free-body diagram of the combined boxes A and B.



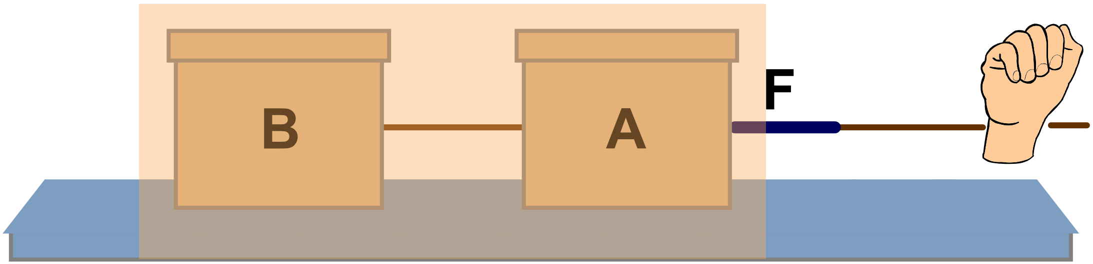
Answer

Problem 4

$F = 40N$; $M_A = 10kg$; $M_B = 12kg$

d) Find the acceleration of the system.

In this case, it's easiest to use the combined mass to find acceleration, though it could be done by looking at the two masses separately.



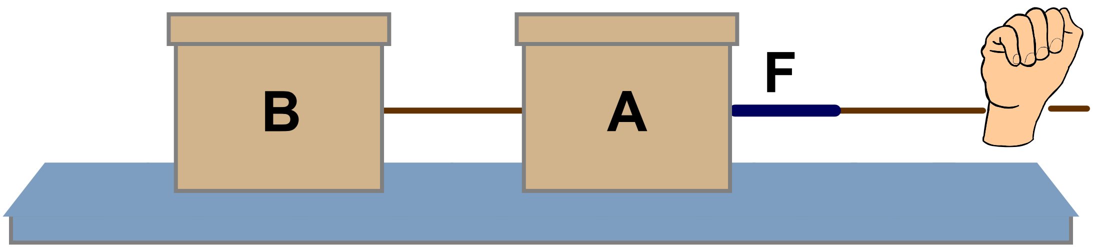
Answer

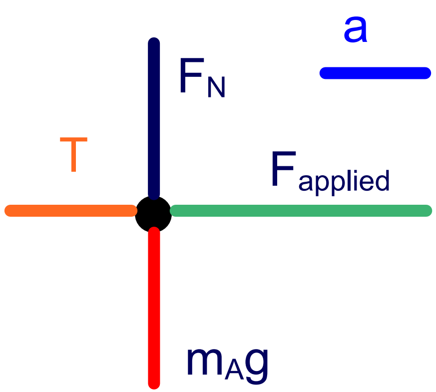
Problem 4

$F = 40N$; $M_A = 10kg$; $M_B = 12kg$

e) Find the tension in the cord.

In this case, we should use the free body diagram for Block A.



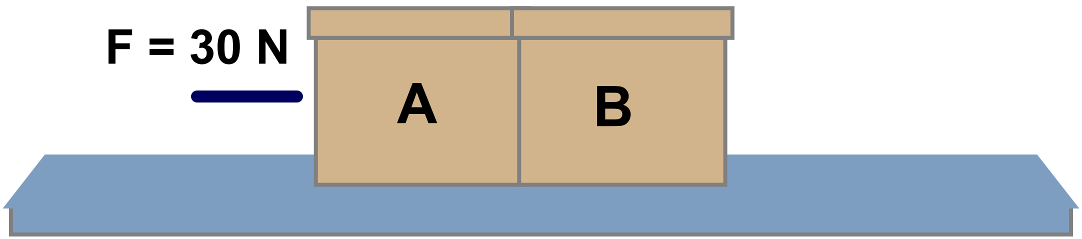


Answer

Problem 5

Two boxes on a table are pushed horizontally with a force of 30.0 N, as shown below. The boxes A and B have masses of 5 kg and 8 kg. Ignore friction.

a) Show the free-body diagram of the box B
b) Show the free-body diagram of the box A
c) Show the free-body diagram of combined boxes A and B
c) Find the acceleration of the system.
d) Find the force of A on B

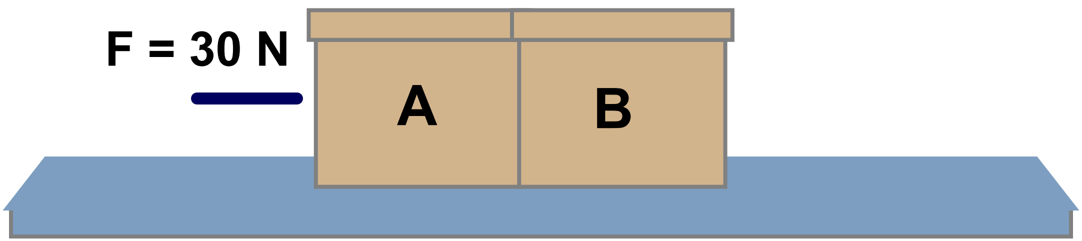


Hint: Use the same approach used for Problem 4.

Problem 5

Two boxes are place on a table. A person pushes horizontally on box A with force F = 30.0 N. The boxes A and B have masses of 5 kg and 8 kg. Ignore friction between the boxes and the tabletop.

a) Show the free-body diagram of the box B.

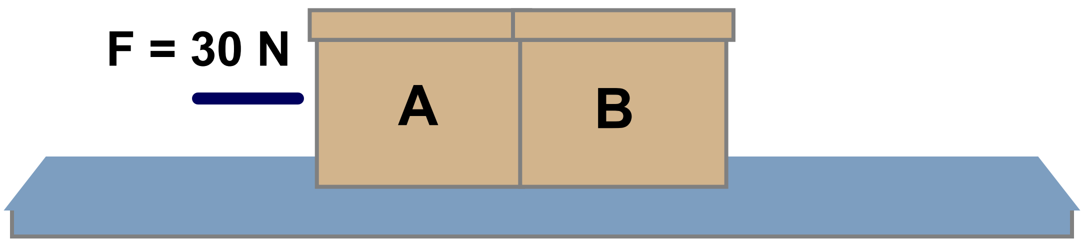


Answer

Problem 5

Two boxes are place on a table. A person pushes horizontally on box A with force F = 30.0 N. The boxes A and B have masses of 5 kg and 8 kg. Ignore friction between the boxes and the tabletop.

a) Show the free-body diagram of the box B.

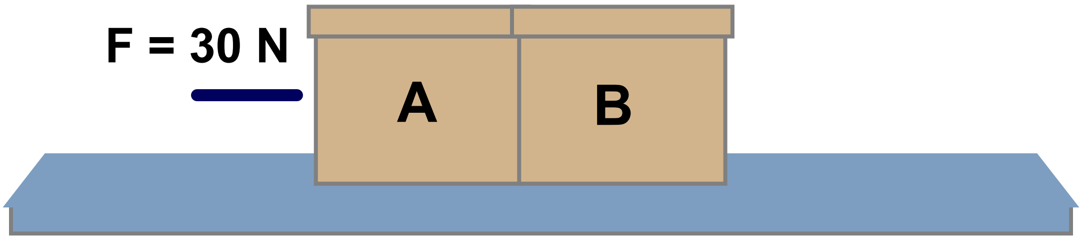


Answer

Problem 5

Two boxes are place on a table. A person pushes horizontally on box A with force F = 30.0 N. The boxes A and B have masses of 5 kg and 8 kg. Ignore friction between the boxes and the tabletop.

c) Find the acceleration of the system.

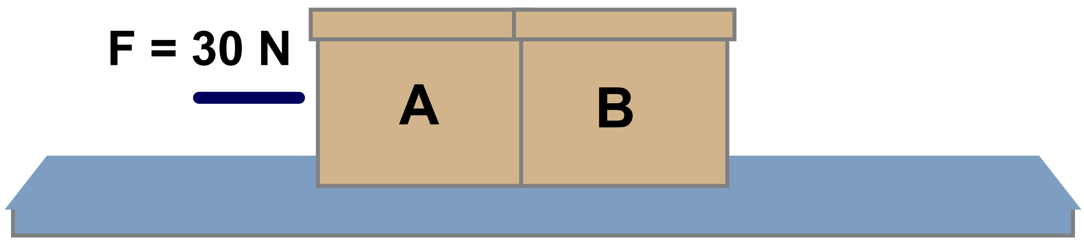


Answer

Problem 5

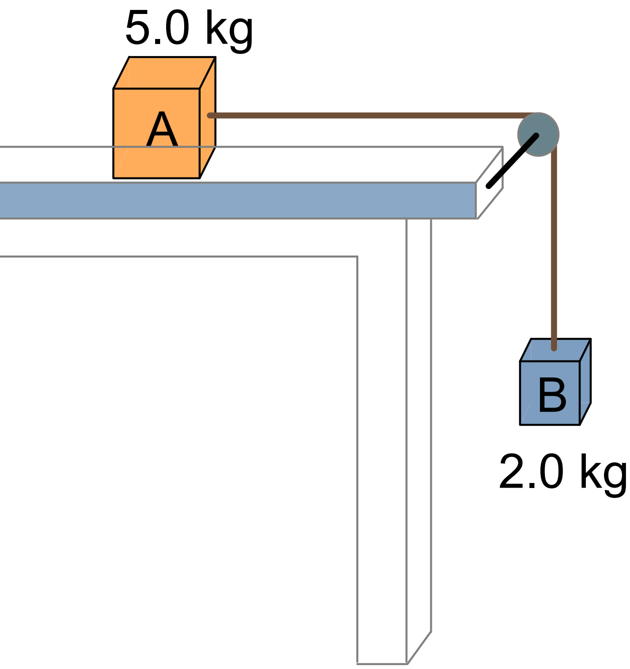
Two boxes are place on a table. A person pushes horizontally on box A with force F = 30.0 N. The boxes A and B have masses of 5 kg and 8 kg. Ignore friction between the boxes and the tabletop.

d) Find the force of A on B



Answer

Problem 6



Two boxes are connected by a cord running over a pulley. The coefficient of kinetic friction between box A and the table is 0.2

a) Show the free-body diagrams of box A and box B

b) Find the acceleration of the system of two boxes

c) Find the tension in the cord

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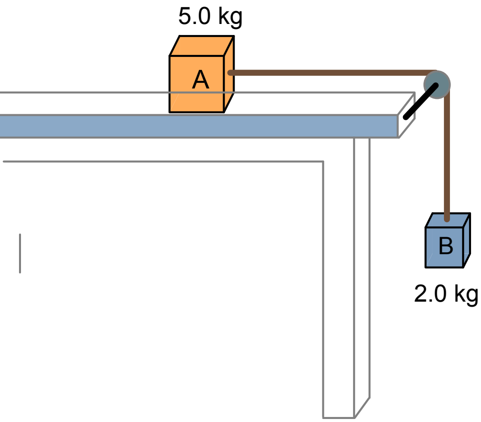
Hint: Use the same approach as Problem 3.

Problem 6

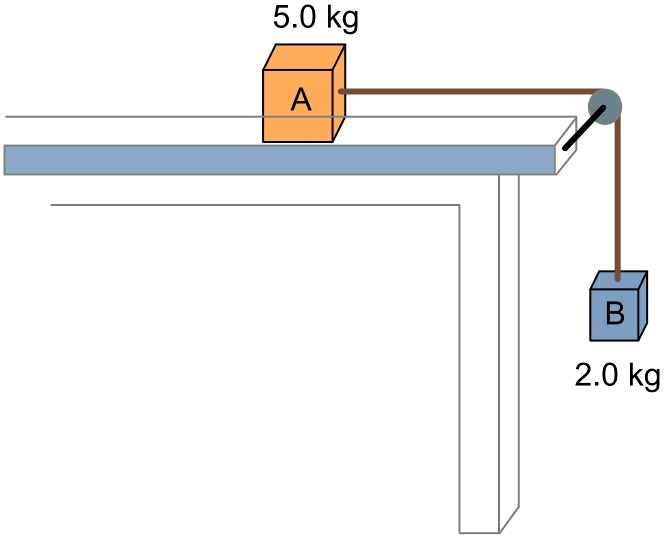


Two boxes are connected by a cord running over a pulley. The coefficient of kinetic friction between box A and the table is 0.2

a) Draw the free-body diagrams for box A and box B.

Answer

Problem 6

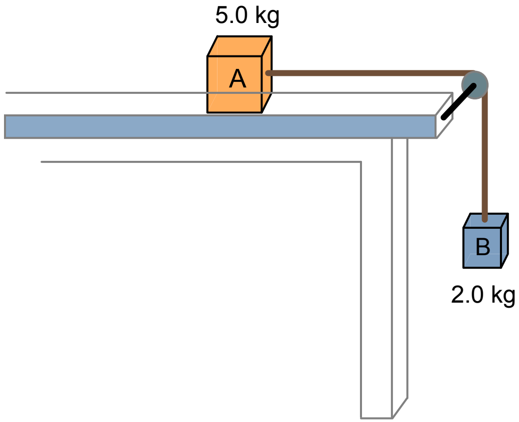


Two boxes are connected by a cord running over a pulley. The coefficient of kinetic friction between box A and the table is 0.2

b) Find the acceleration of the system of two boxes

Answer

Problem 6



Two boxes are connected by a cord running over a pulley. The coefficient of kinetic friction between box A and the table is 0.2

c) Find the tension in the cord

Answer