Chapter 4

Forces and Newton's Laws of Motion

Exam 1 Scores

Mean score was ~ 9.5

What is that in a grade 4.0, 3.5, …?

< 5 :	1.5 or lower
5 :	2.0
6, 7 :	2.5
8,9,10,11:	3.0
12,13 :	3.5
>13 :	4.0

Solutions are posted.

Exam 1 most "difficult" problem

A car starts from rest and accelerates at a constant rate in a straight line. In the first second the car moves a distance of 4.0 meters. How fast will the car be moving at the end of the second second?

A) 4.0 m/s
B) 16 m/s
C) 2.0 m/s
D) 32 m/s
E) 8.0 m/s
F) 0.25 m/s
G) 1.0 m/s
H) 0.5 m/s

Plan

Known are $v_0 = 0$, $\Delta x = 4.0\text{m}$, $t = 1\text{s}$

Find the constant acceleration with

$$\Delta x = v_0 t + \tfrac{1}{2} a t^2$$

Acceleration is the same throughout the motion

With that a, determine the velocity at $t = 2\,\text{s}$

$$v = v_0 + at$$

Exam 1 most "difficult" problem

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H) 0.5 m/s

$$v_0 = 0,\ \Delta x = 4.0\text{m}\ ,\quad t = 1\text{s}$$

$$\Delta x = v_0 t + \tfrac{1}{2} a t^2 \quad \text{gets the acceleration (constant)}$$

$$a = \frac{2\Delta x}{t^2} = \frac{8.0\text{ m}}{1\text{ s}^2} = 8.0\text{ m/s}^2$$

<u>Acceleration is the same throughout the motion</u>

$$v = v_0 + at \quad \text{determines the velocity at } t = 2\text{s}$$

$$v = at = (8.0\text{ m/s}^2)(2\text{s}) = \underline{16\text{m/s}}$$

Chapter 4

Forces and Newton's Laws of Motion

A ***force*** is a push or a pull acting on an object. A force is a vector!

Contact forces arise from physical contact, and are due to a stretch or compression at the point of contact.

Action-at-a-distance forces do not require contact and include gravity and forces due to charged particles

4.1 The Concepts of Force and Mass

Arrows are used to represent force vectors. The length of the arrow is proportional to the magnitude of the force.

15 N = fifteen newtons

5 N

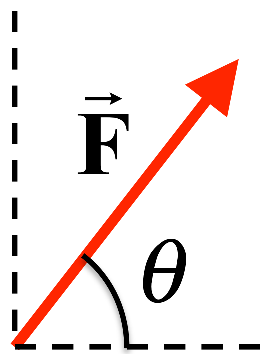
force

10 N ~ 2.2 lbs

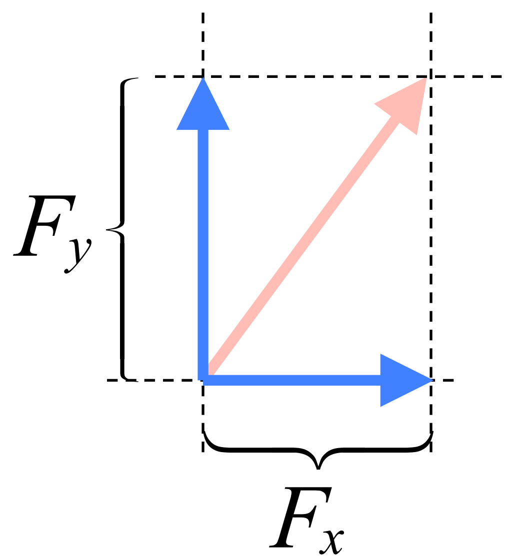
4.1 The Concepts of Force and Mass

Bold letter with arrow is the symbol, $\vec{\mathbf{F}}$, for a force vector: has magnitude and direction.

Direction is given as an angle, θ, or coded in components, F_x, F_y.



$$F = |\vec{\mathbf{F}}|$$



$$\boxed{\begin{aligned} F_x &= F\cos\theta \\ F_y &= F\sin\theta \end{aligned}}$$

$$\boxed{\begin{aligned} \theta &= \tan^{-1}(F_y / F_x) \\ F &= \sqrt{F_x^2 + F_y^2} \end{aligned}}$$

Mass of an object is a measure of the number and type of atoms within the object.

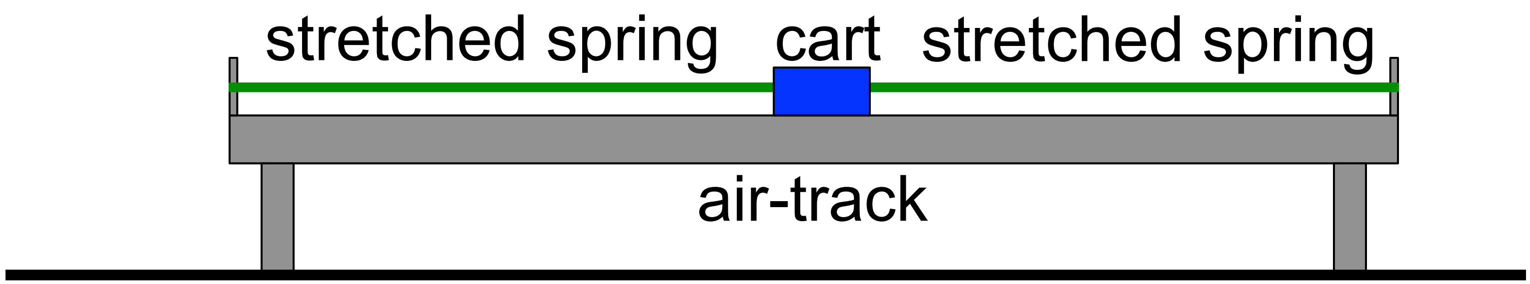
Mass can be measured without resorting to gravity/weight.

A spring will oscillate a mass with an oscillation period,

$$T \propto \sqrt{m}. \qquad (\propto \text{ means proportional to})$$

If the period is twice as long, the mass is 4 times bigger.

Device to measure a mass anywhere in the universe



a planet or moon
or a big spaceship (air-track unnecessary)

These springs can be taken anywhere in the universe and used to measure the mass of any cart. Also, the stretching of these springs can be used to define the unit of force.

SI Unit of Mass: kilogram (kg)

Newton's First Law

An object continues in a state of rest or in a state of motion at a constant speed *along a straight line*, unless compelled to change that state by a net force.

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

Net Force acting on ONE object

Mathematically, the net force is written as

$$\sum_{i=1}^{N} \vec{\mathbf{F}}_i = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 + \vec{\mathbf{F}}_3 + \cdots + \vec{\mathbf{F}}_N$$

where the Greek letter sigma denotes the vector sum of all forces acting on an object.

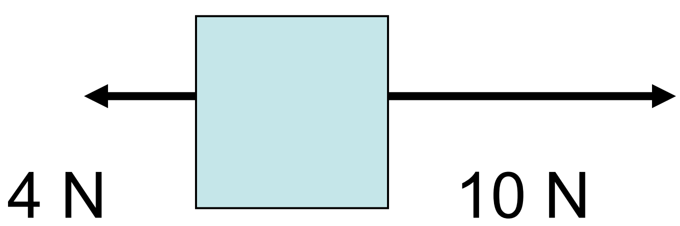
ONE object!

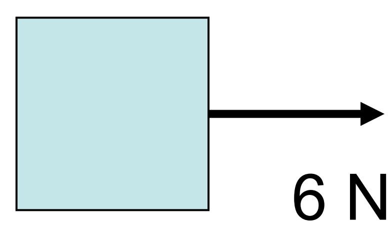
4.2 Newton's Laws of Motion (First Law)

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

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

Individual Forces | Top views | Net Force

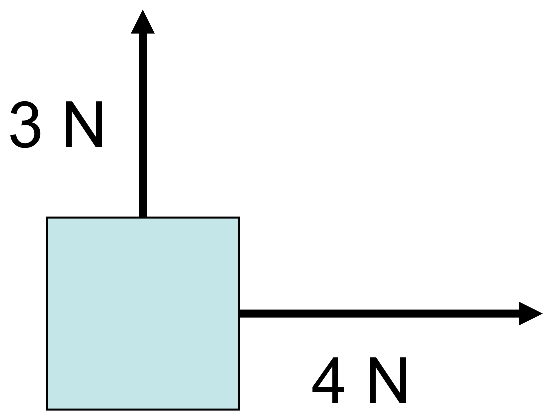




4.2 Newton's Laws of Motion (First Law)

Individual Forces

Top view

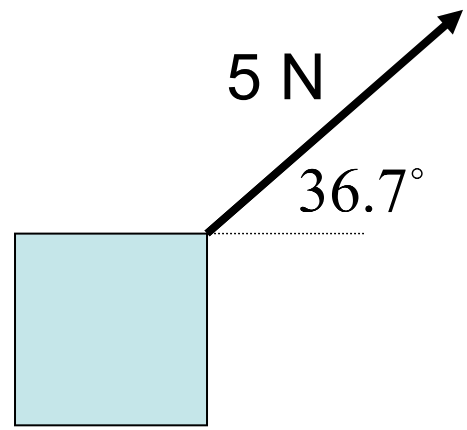


No friction

No Gravity

Net Force

Top view



θ is an angle with respect to x-axis

$$\tan\theta = \frac{F_y}{F_x} \quad \Rightarrow \quad \theta = \tan^{-1}\left(\frac{F_y}{F_x}\right)$$

$$\theta = \tan^{-1}\left(\frac{3}{4}\right) = 36.7^\circ$$

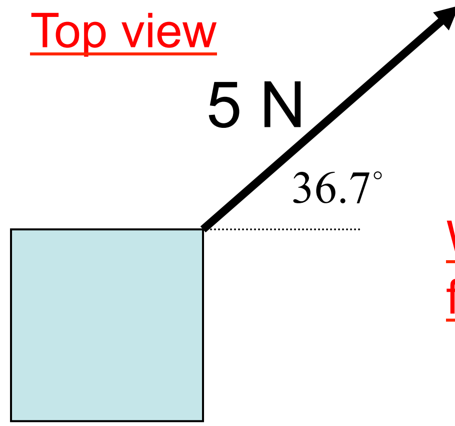
4.2 Newton’s Laws of Motion (First Law)

Net Force

Top view

No friction

No Gravity

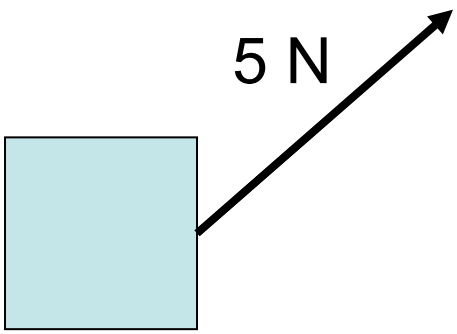


You will see this
in most textbooks.

Why does the picture show the
force vector attached to a corner ?

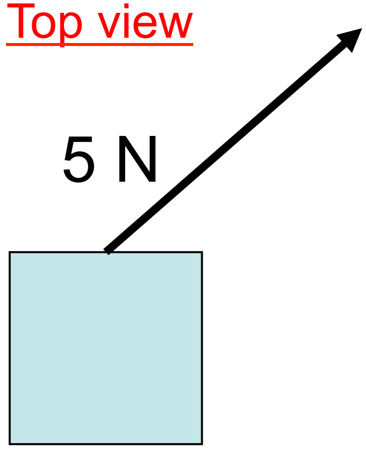
Why not

Top view



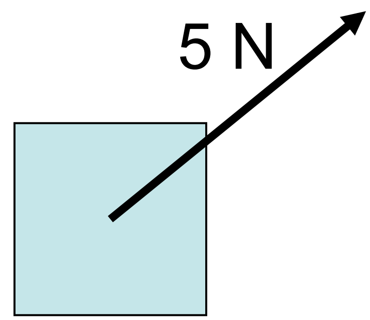
or this

Top view



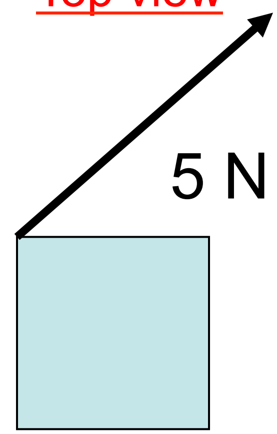
or this

Top view



or this

Top view



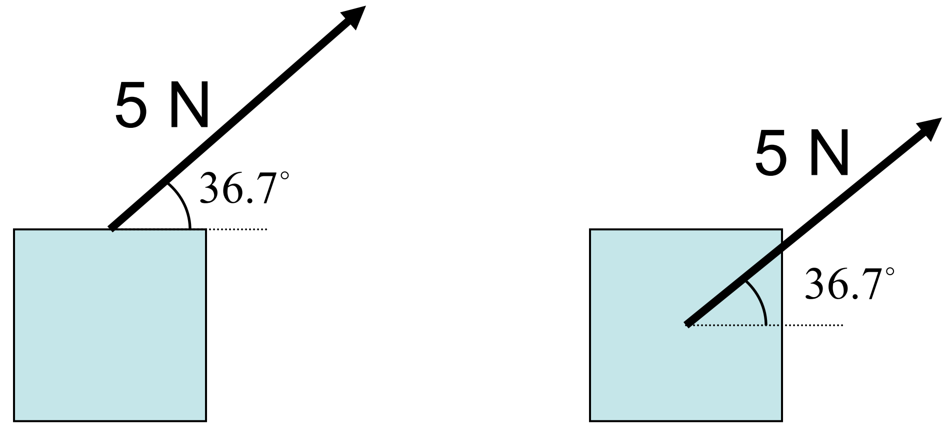
Best would be this,
attached to the center of object.

4.2 Newton's Laws of Motion (First Law)

No friction

No Gravity

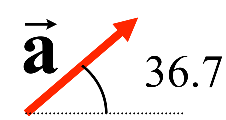
Top view



Both drawings lead to the same linear motion of the object

The object will not maintain a constant $\underbrace{\text{speed \& direction}}_{\text{velocity}}$.

Object accelerates in this direction:



4.2 Newton's Laws of Motion (First Law)

Newton's 1st law: for an object to remain at rest, or move with constant speed & direction, the Net Force acting on it must be equal to ZERO.

So

Newton's 1st law: if the Net Force acting on a object is NOT ZERO, the velocity (magnitude, or direction, or both) must change.

4.2 Newton's Laws of Motion (First Law)

Newton's 1st law is often called the law of inertia.

Inertia is the natural tendency of an object to remain at rest or in motion at a constant speed along a straight line.

The *mass* of an object is a quantitative measure of inertia.

An *inertial reference frame* is one in which Newton's law of inertia is valid.

All accelerating reference frames are non-inertial.

Examples of non-inertial reference frames:
In an accelerating car, accelerating elevator, accelerating rocket, in a centrifuge ($\vec{\mathbf{a}}_c$ inward) and in a car making a turn (direction change) …

Warning:

Newton's 1st law can appear to be violated if you don't recognize the existence of contact forces.

Newton's 1st law: for an object to *remain at rest*, or *move with constant speed & direction*, the Net Force acting on it must be ZERO.

Examples of Newton's first law
(4 clicker questions):

A mass hanging from a string.
A mass at rest on a table.
A mass at rest on a ramp.
A mass sliding on a table.

Clicker Question 4.1

A mass hanging from a string.

Gravity applies a 100 N gravitational force to the object. What force component does the string apply to the object?

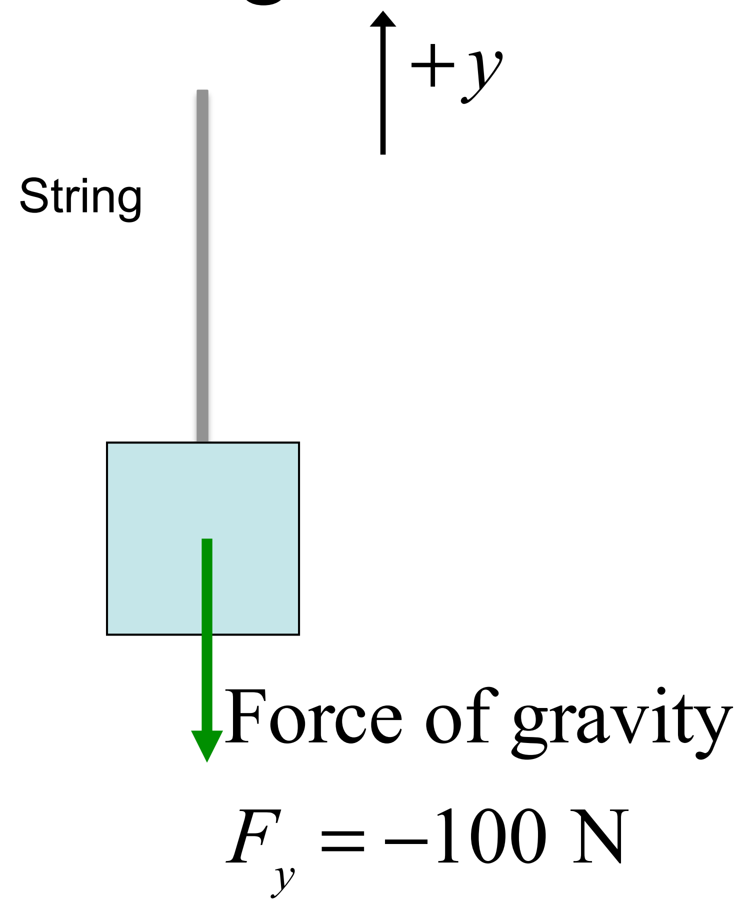
a) string $F_y = -100$ N

b) string $F_y = +100$ N

c) string $F_y = \;\; 0$ N

d) string $F_y = \;\; 1$ N

e) A string can't make a force



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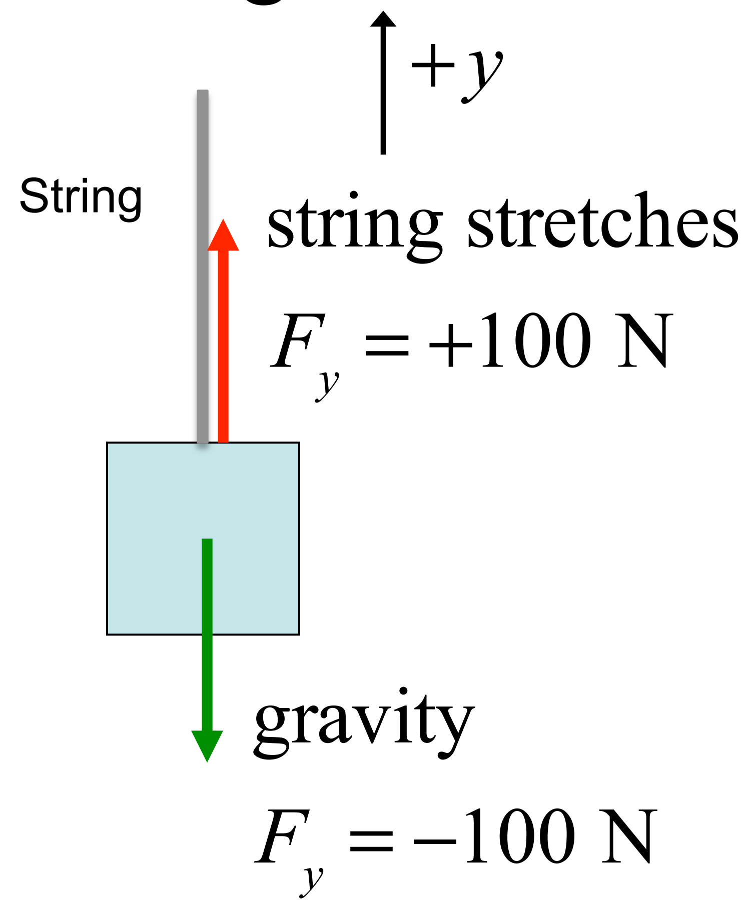
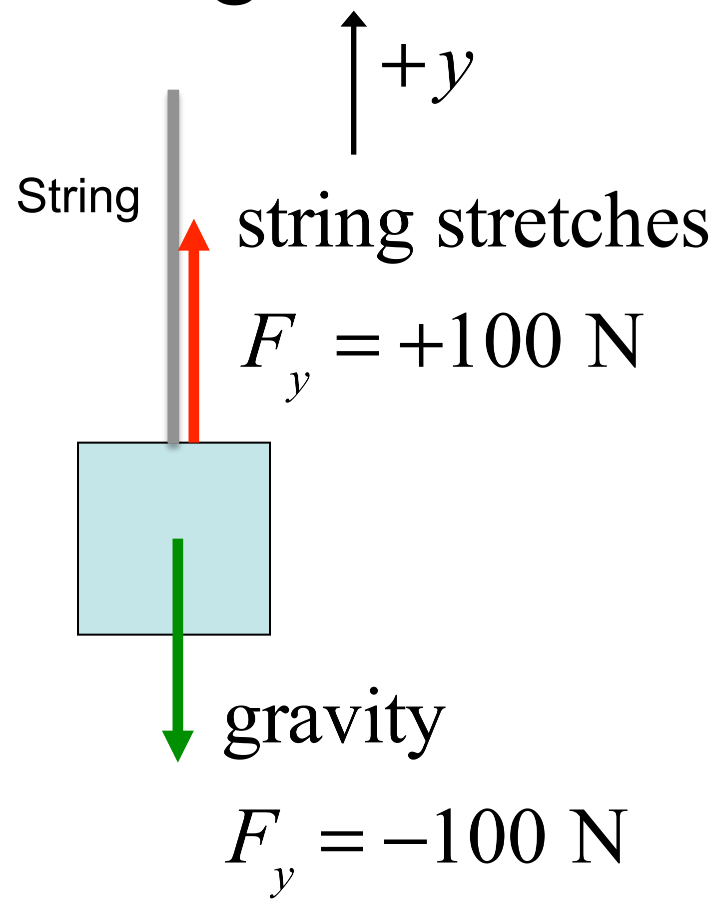


Clicker Question 4.1

A mass hanging from a string.

How does the string "know" how much force to apply to EXACTLY balance the gravity force?

As you slowly let the mass go, the string starts to stretch. The more it streches the harder it pulls up. When you let go, it has stretched just enough to pull back with EXACTLY the right amount of force.



Clicker Question 4.2

A mass resting on a table.

At rest: Net force must be zero

Gravity applies a 100 N gravitational force to the object. What force does the table apply to the object?

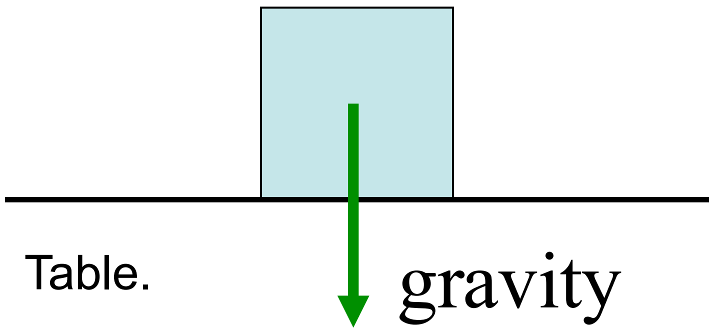
a) table $F_y = -100$ N

b) table $F_y = +100$ N

c) table $F_y = 0$ N

d) table $F_y = 1$ N

e) A table can't make a force



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c) table $F_y = \quad 0\text{ N}$

d) table $F_y = \quad 1\text{ N}$

e) A table can't make a force

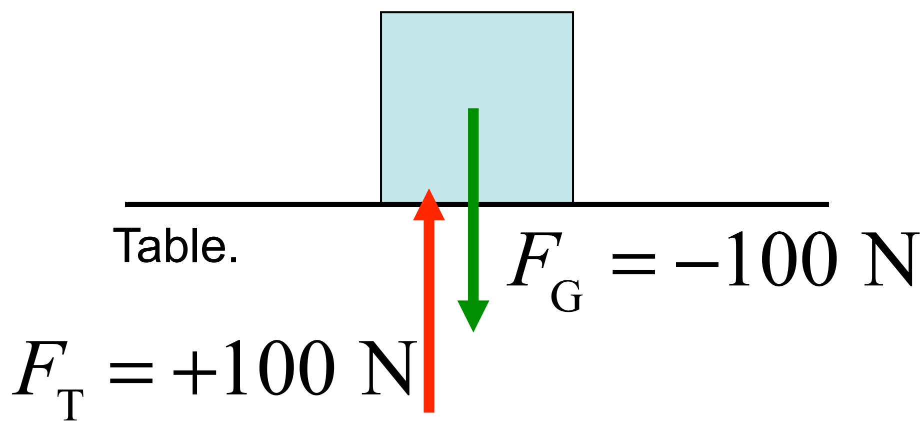


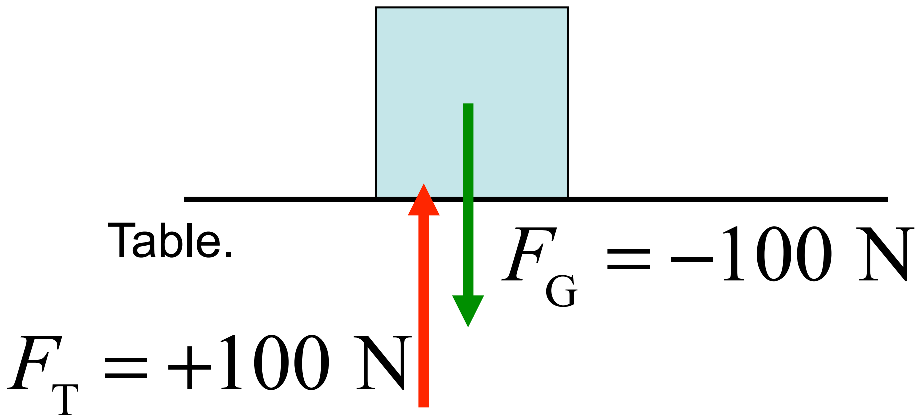
Table presses on the mass

Clicker Question 4.2

A mass resting on a table.

At rest: Net force must be zero

How does the table “know” how much force to apply to EXACTLY balance the gravity force?



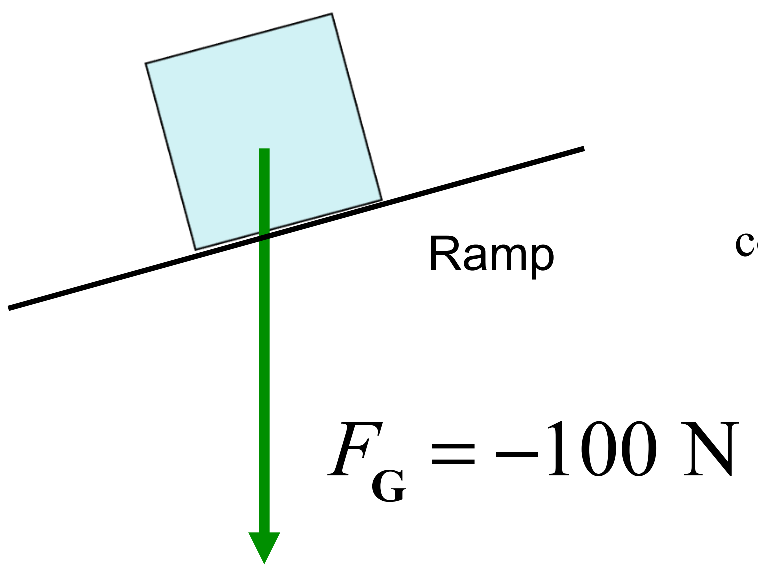
Slowly you put the mass on the table. The table starts compress. More compression, harder the table pushes up. When you let go, it has compressed enough to push back with EXACTLY the right amount of force.

Table presses on the mass

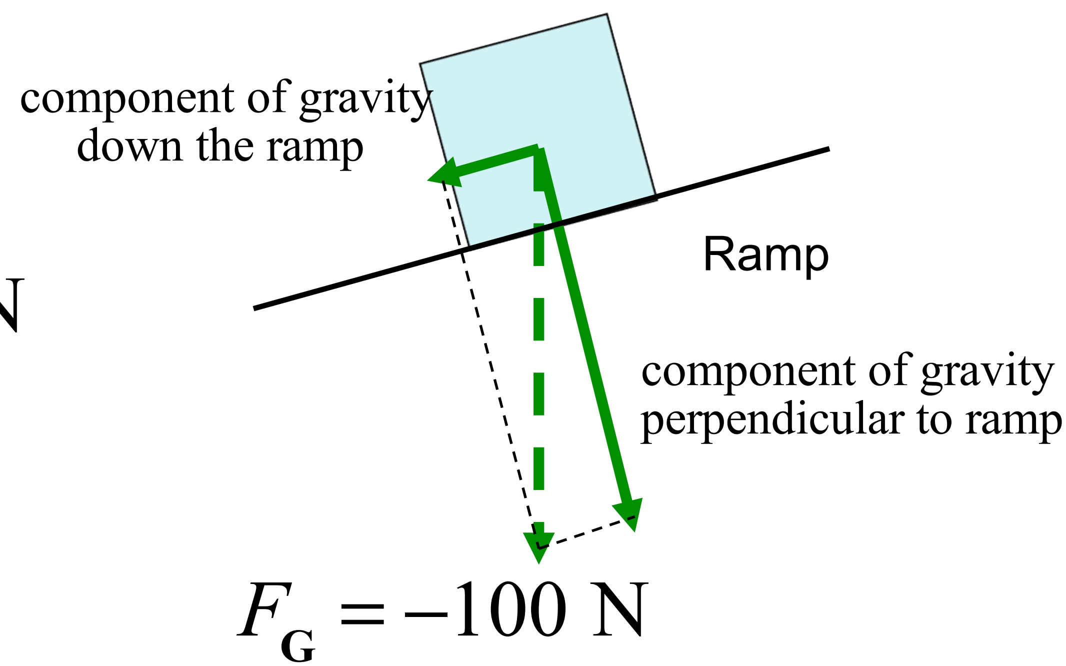
Called the NORMAL force (perpendicular)

A mass at rest on a ramp.

Gravity applies a 100 N gravitational force to an object at rest on a 15° ramp.



Component of gravity pulls the mass down the the ramp

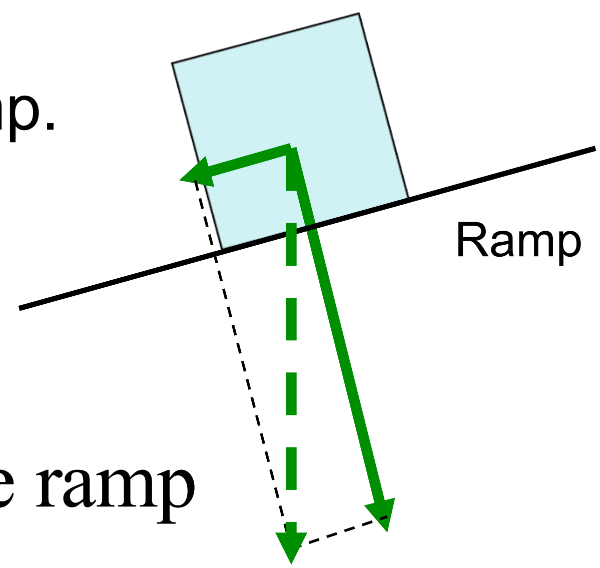


Clicker Question 4.3

A mass at rest on a ramp.

At rest: Net force must be zero

Gravity applies a 100 N gravitational force to an object at rest on a 15° ramp. The friction between ramp and object applies a force on the mass in what direction?



$$F_G = -100 \text{ N}$$

a) Frictional force > 100 N, up the ramp

b) Frictional force = 100 N, up the ramp

c) Frictional force = 100 N, down the ramp

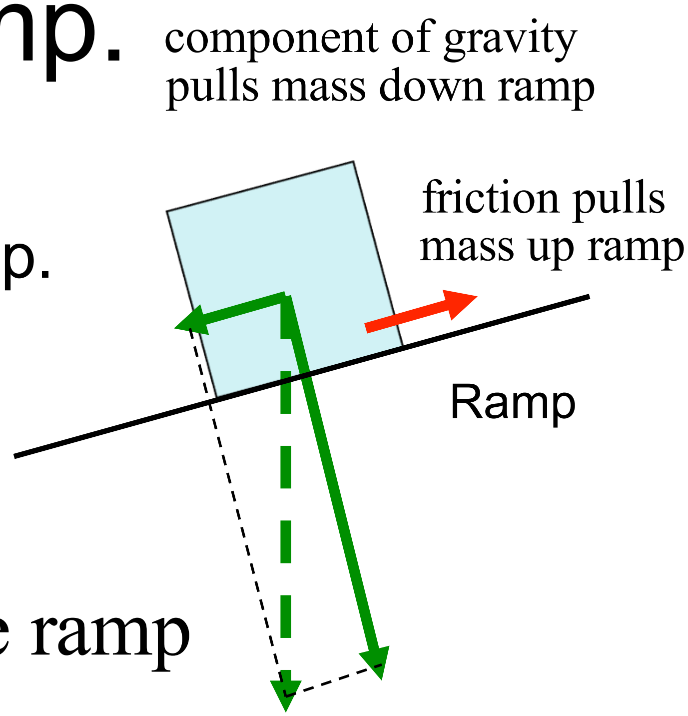
d) Frictional force < 100 N, up the ramp

e) A ramp can't make a force

Clicker Question 4.3

A mass at rest on a ramp.

Gravity applies a 100 N gravitational force to an object at rest on a 15° ramp. The friction between ramp and object applies a force on the mass of what magnitude and direction?



$F_G = -100\ \text{N}$

a) Frictional force > 100 N, up the ramp

b) Frictional force = 100 N, up the ramp

c) Frictional force = 100 N, down the ramp

d) Frictional force < 100 N, up the ramp

e) A ramp can't make a force

At rest: Net force must be zero

Clicker Question 4.3

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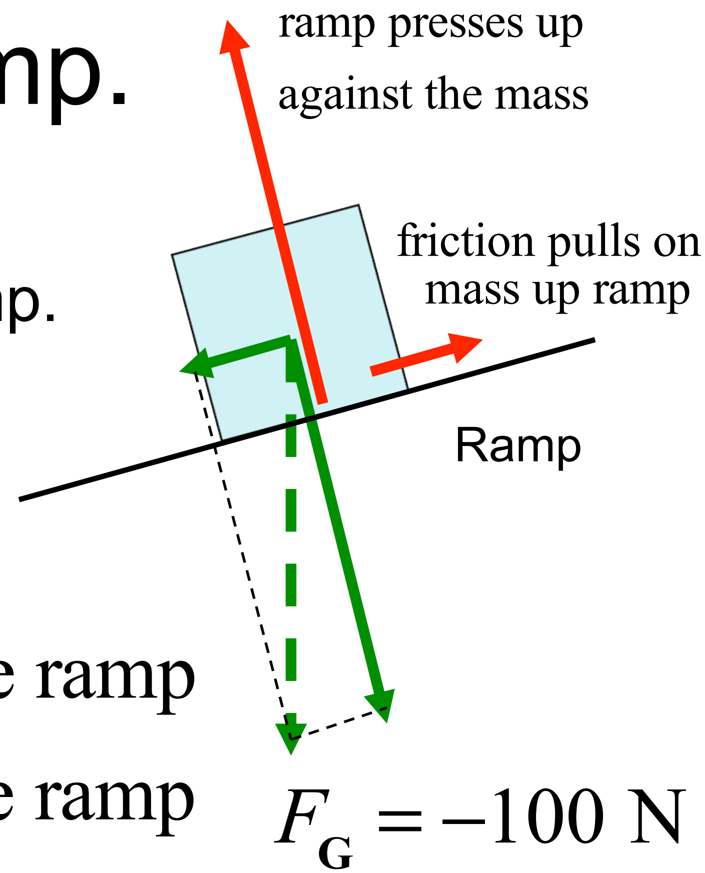


a) Frictional force > 100 N, up the ramp

b) Frictional force = 100 N, up the ramp

c) Frictional force = 100 N, down the ramp

d) Frictional force < 100 N, up the ramp

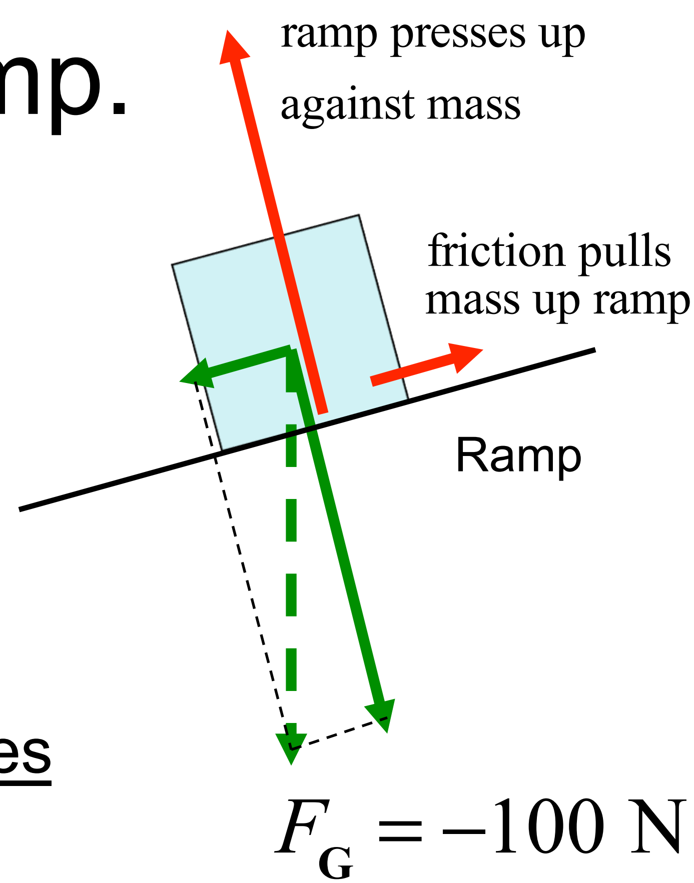
e) A ramp can't make a force

At rest: Net force must be zero

Clicker Question 4.3

A mass at rest on a ramp.

How does the friction between the mass and the table “know” how much force will EXACTLY balance the gravity force pulling the mass down the ramp?



As you slowly put the mass on the ramp, the ramp compresses & <u>stretches along the ramp</u> as gravity *tries* to slide the mass down the ramp. When you let go, the ramp has stretched enough to push on the mass with EXACTLY the right amount of force up the ramp.

At rest: Net force must be zero