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!

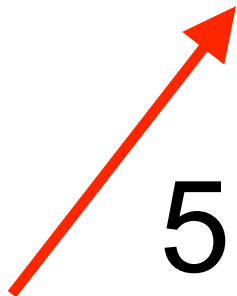***Contact forces*** arise from physical contact, and are due to a stretch or compression at the point of contact.

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

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
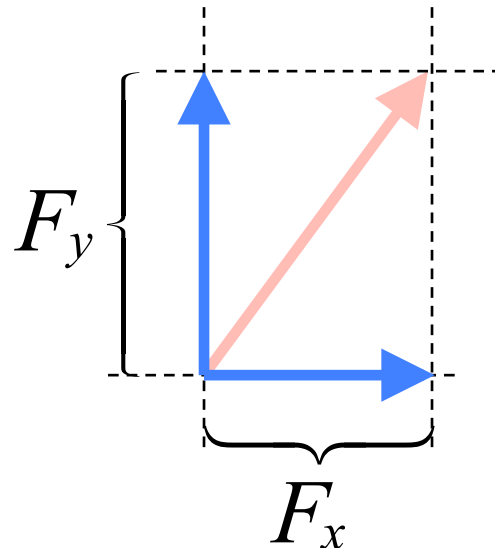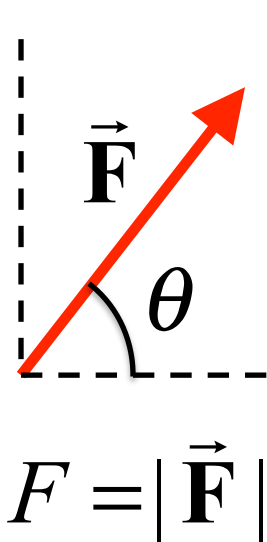
5 N ~ 1 lb

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.

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

$$F_x = F\cos\theta$$

$$F_y = F\sin\theta$$

$$\theta = \tan^{-1}(F_y/F_x)$$

$$F = \sqrt{F_x^2 + F_y^2}$$

*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,

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

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

Device to measure a mass anywhere in the universe

stretched spring   cart   stretched spring
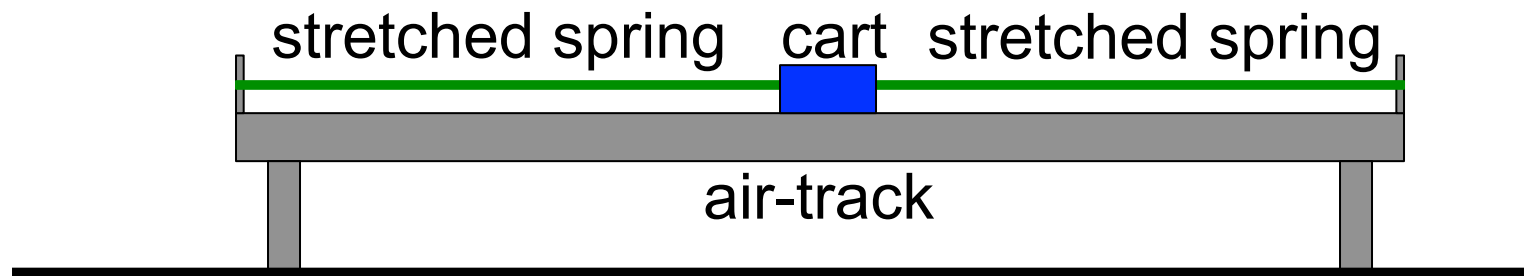
air-track

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!

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 N   10 N   6 N
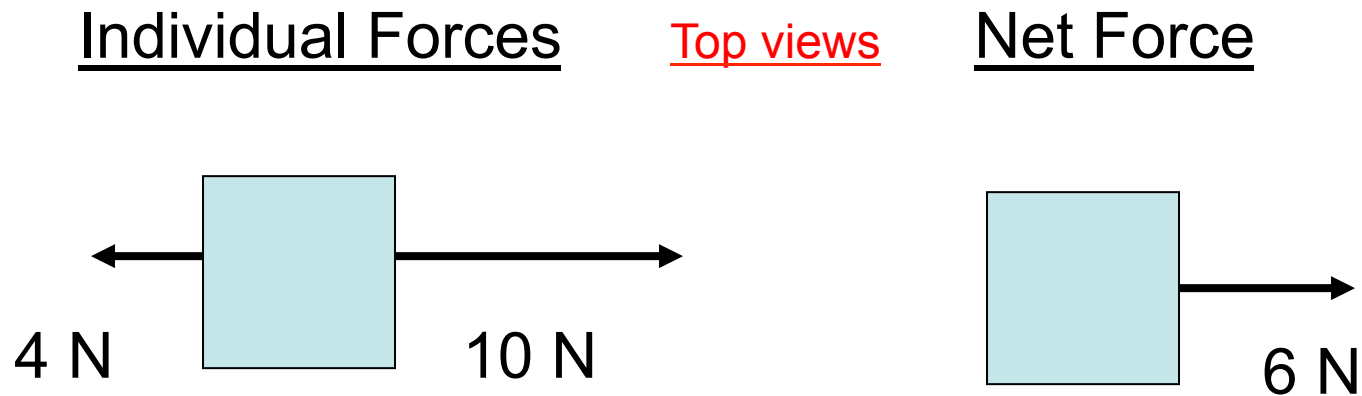
4.2 *Newton's Laws of Motion (First Law)*

Individual Forces

No friction

No Gravity

3 N

4 N

Net Force

Top view

5 N

36.7°
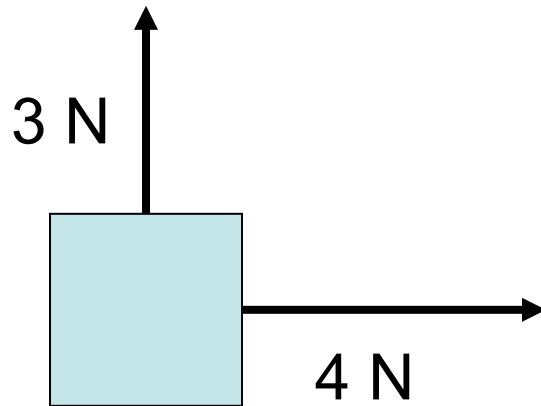
θ is an angle with respect to x-axis

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

$$\theta = \tan^{-1}\left(\frac{3}{4}\right) = 36.7°$$
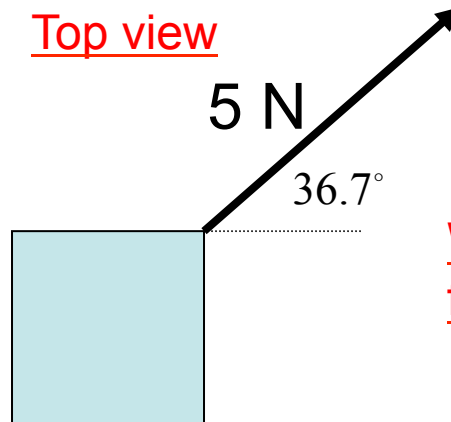
4.2 *Newton's Laws of Motion (First Law)*

Net Force

Top view

No friction

No Gravity

5 N

36.7°

You will see this
in most textbooks.
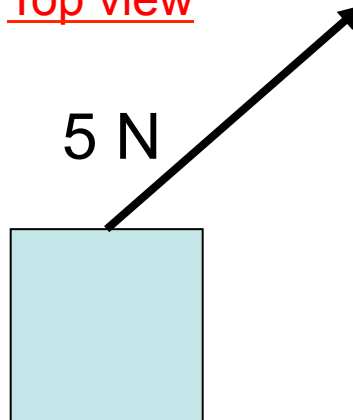
Why does the picture show the
force vector attached to a corner ?

Why not
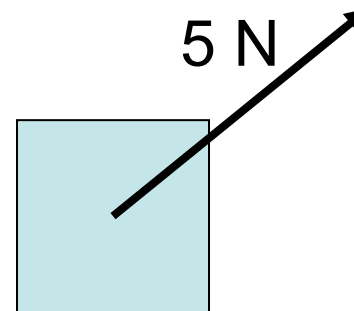
Top view

5 N

or this

Top view

5 N

or this

Top view

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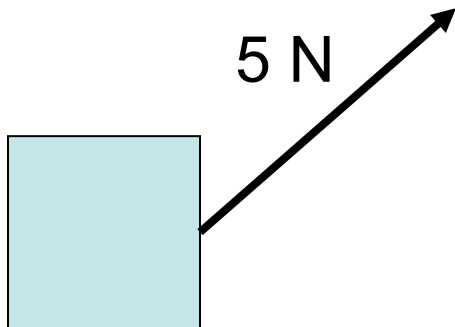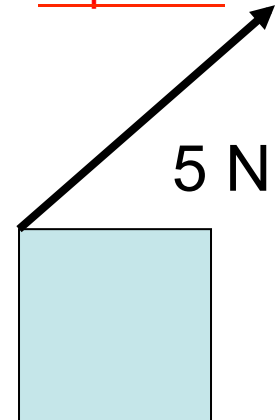
Best would be this,
attached to the center of object.

or this

Top view

5 N

No friction

No Gravity

Top view

5 N

36.7°

5 N

36.7°
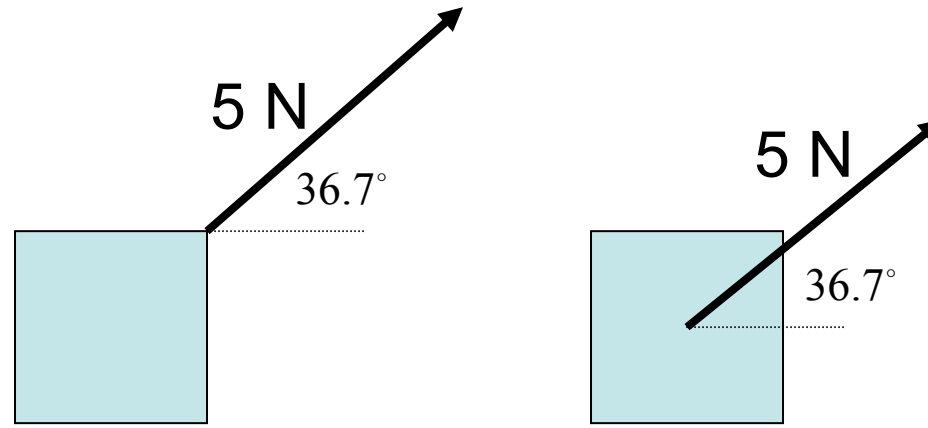
Both drawings lead to the same linear motion of the object

The object will not maintain a constant speed & direction.

velocity

The object will accelerate in this direction: $\vec{a}$

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

So

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

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.

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 (4 clicker questions):

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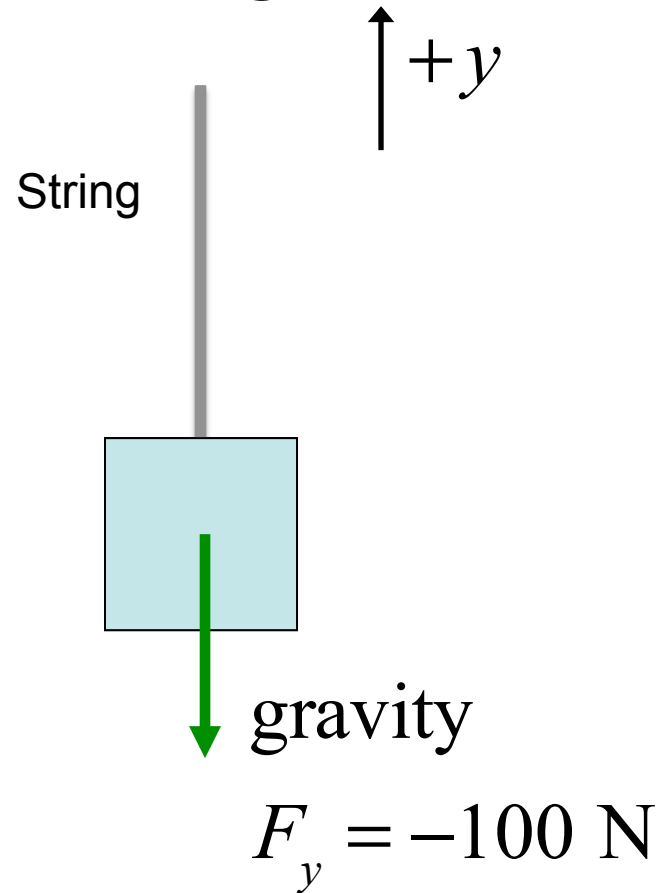
A mass at rest on a table.

A mass at rest on a ramp.

A mass sliding on a table.

A mass hanging from a string.

$+y$

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

String

a) string $F_y = -100$ N

b) string $F_y = +100$ N

c) string $F_y = \quad 0$ N

d) string $F_y = \quad 1$ N

e) A string can't make a force

gravity

$F_y = -100$ N

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?
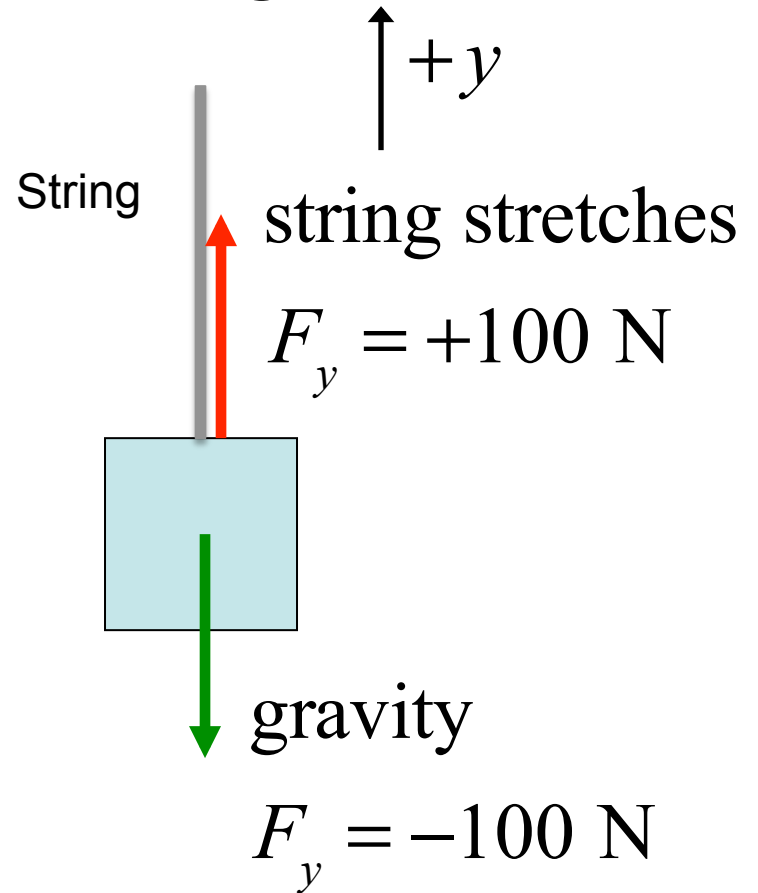
a) string $F_y = -100$ N

b) string $F_y = +100$ N

c) string $F_y = \quad 0$ N

d) string $F_y = \quad 1$ N

e) A string can't make a force

$+y$

String

string stretches

$F_y = +100$ N

gravity

$F_y = -100$ N
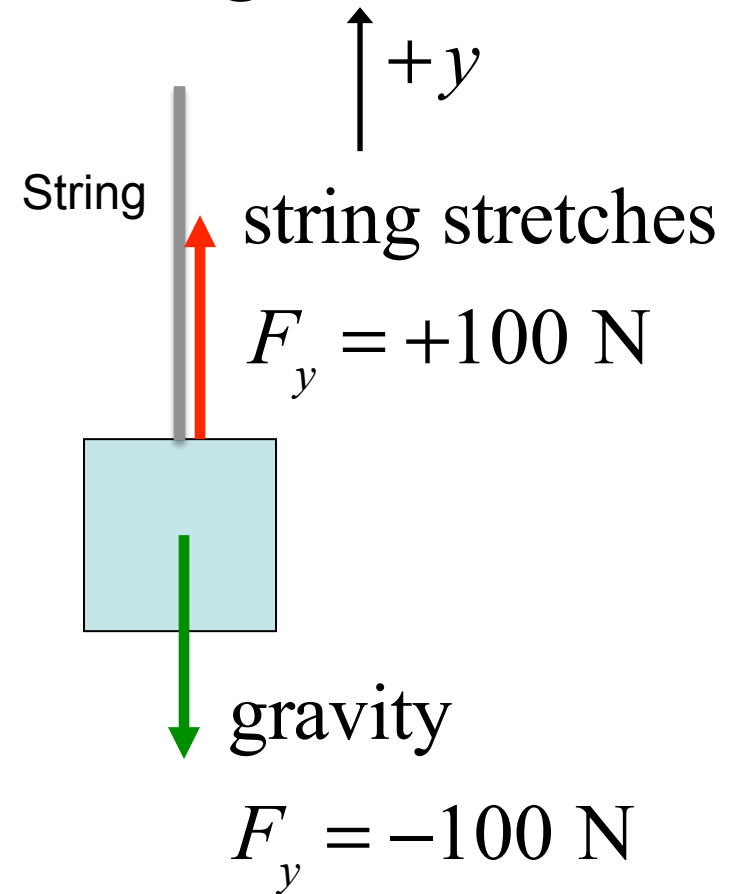
A mass hanging from a string.

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.

$+y$

String

string stretches

$F_y = +100 \text{ N}$

gravity

$F_y = -100 \text{ N}$

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

Table.

gravity

$F_y = -100$ N

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?
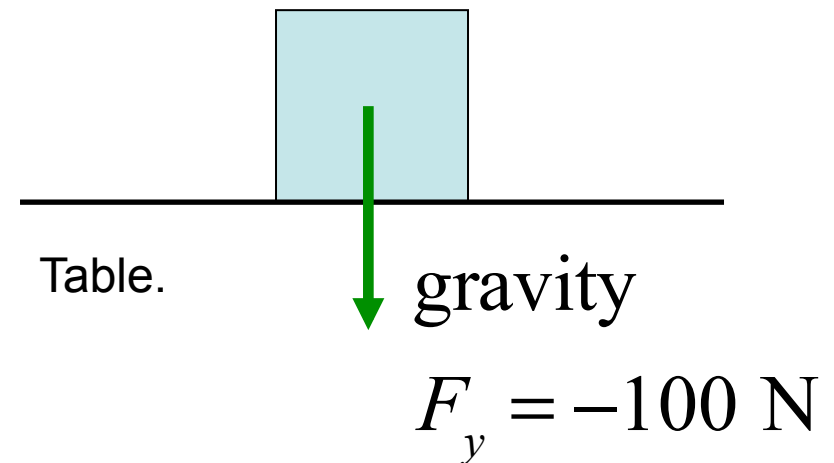
a) table $F_y = -100$ N

b) table $F_y = +100$ N

c) table $F_y = 0$ N

d) table $F_y = 1$ N
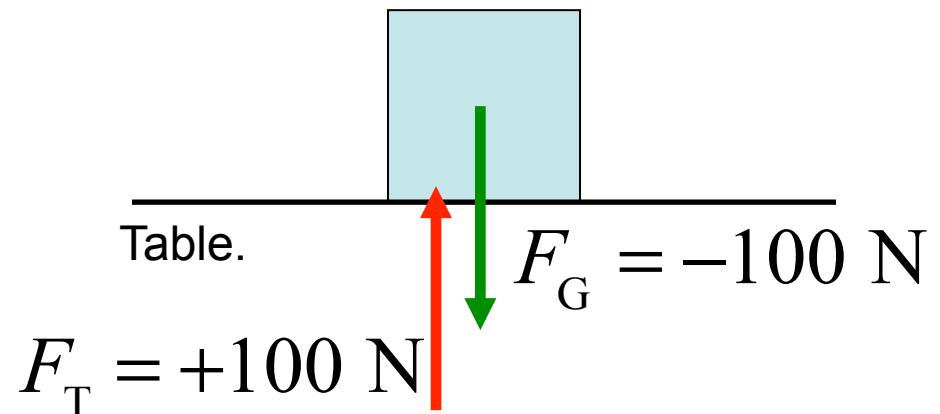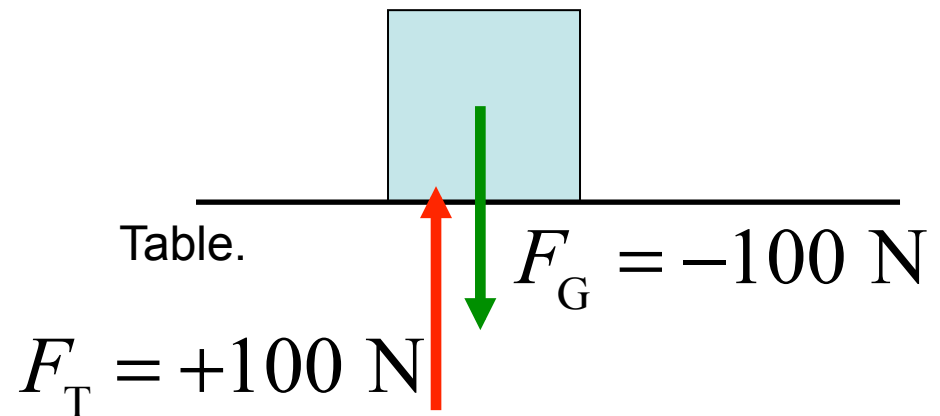
e) A table can't make a force

Table.

$F_G = -100$ N

$F_T = +100$ N

Table presses on the mass

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?

Table.

$F_{G} = -100 \text{ N}$

$F_{T} = +100 \text{ N}$

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.
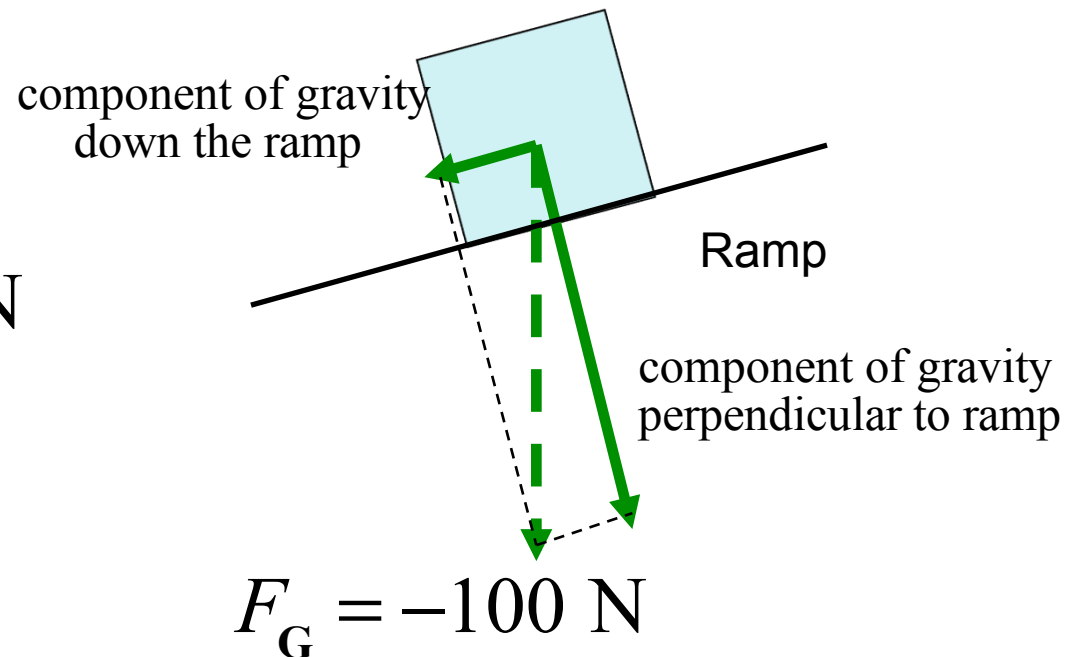
Table presses on the mass Called the NORMAL force (perpendicular)

A mass at rest on a ramp.

Gravity applies a 100 N gravitational
force to an object at rest on a 15° ramp.
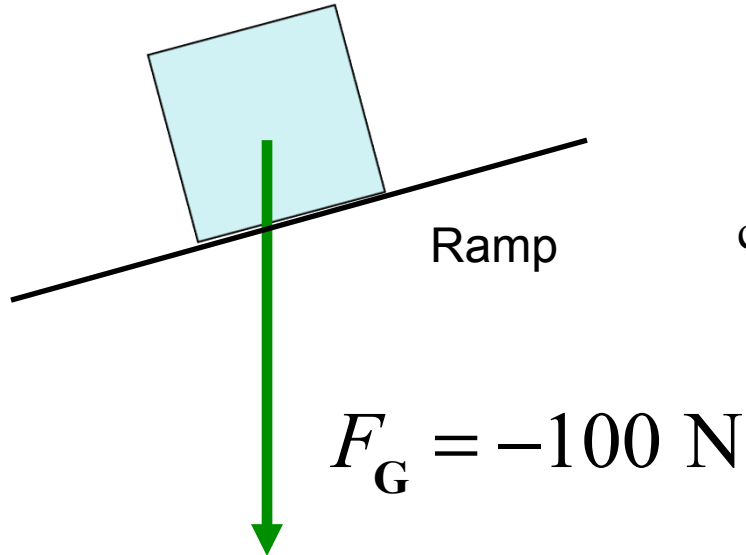
Component of gravity pulls the
mass down the the ramp

Ramp

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

component of gravity
down the ramp

Ramp

component of gravity
perpendicular to ramp

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

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?
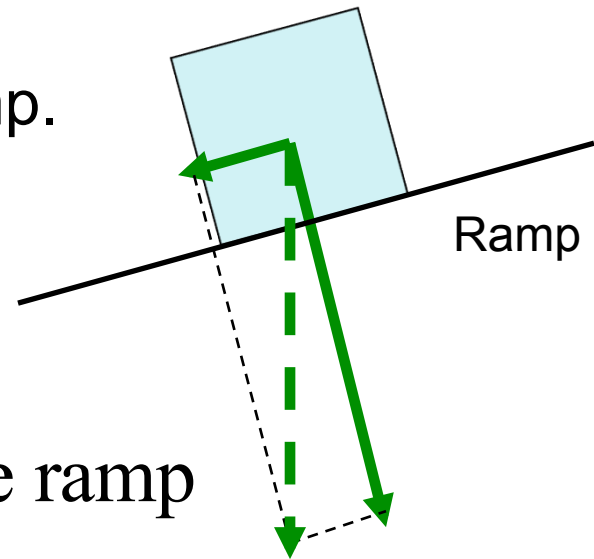
Ramp

$F_G = -100$ 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

A mass at rest on a ramp.
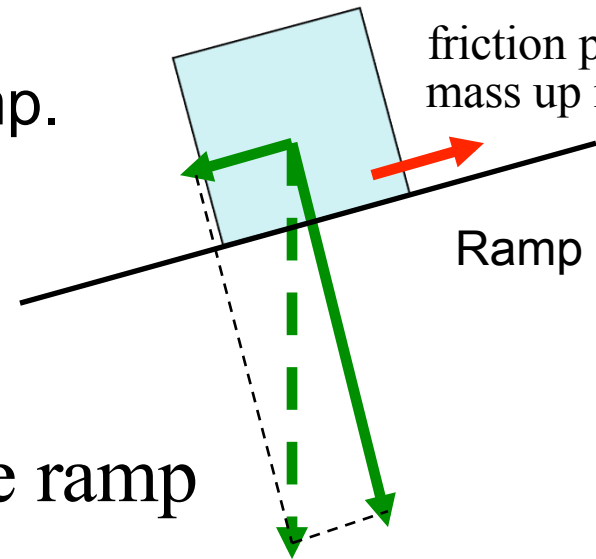
component of gravity
pulls mass down ramp

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?

friction pulls
mass up ramp

Ramp

a) Frictional force > 100 N, up the ramp

b) Frictional force $= 100$ N, up the ramp

$F_G = -100$ N

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

A mass at rest on a ramp.

ramp presses up
against the mass

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?

friction pulls on
mass up ramp

Ramp

a) Frictional force > 100 N, up the ramp

b) Frictional force $= 100$ N, up the ramp

$$F_{\mathbf{G}} = -100 \text{ N}$$

c) Frictional force $= 100$ N, down the ramp

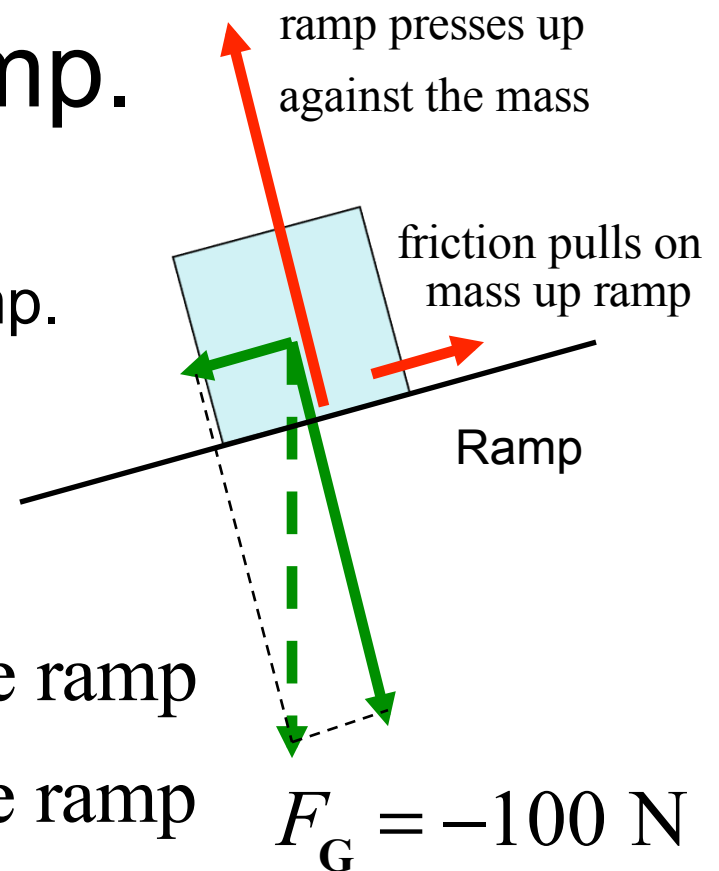d) Frictional force < 100 N, up the ramp

e) A ramp can't make a force

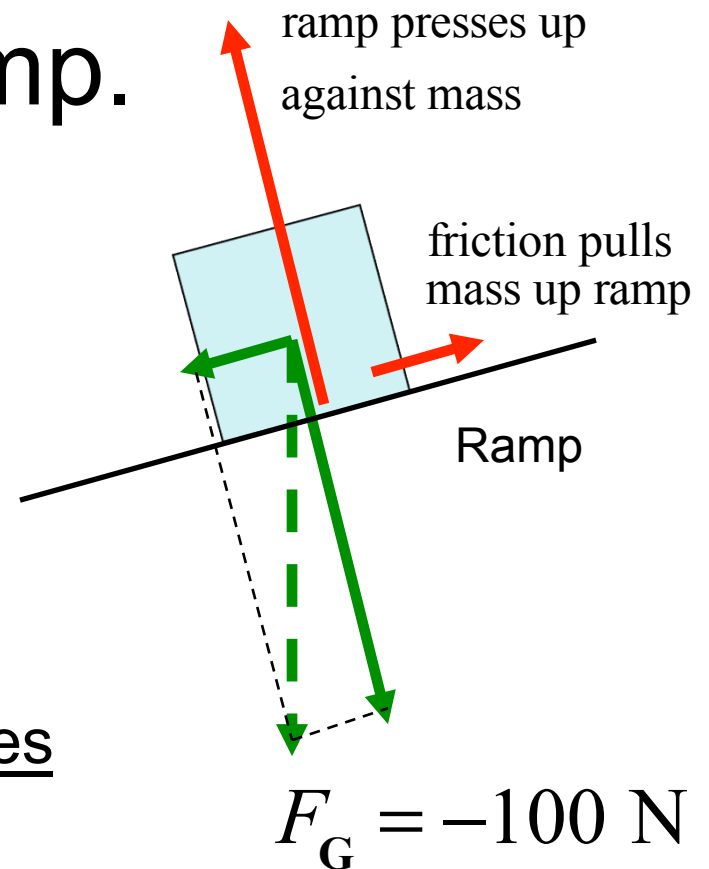At rest: Net force
must be zero

A mass at rest on a ramp.

ramp presses up
against mass

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?

friction pulls
mass up ramp

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.

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

At rest: Net force must be zero