Chapter 4

Forces and Newton's Laws of Motion

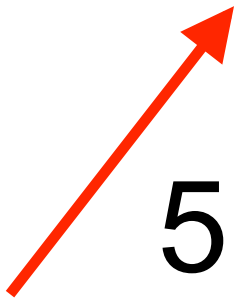
A ***force*** is a push or a pull acting on an object. A force is a vector!

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

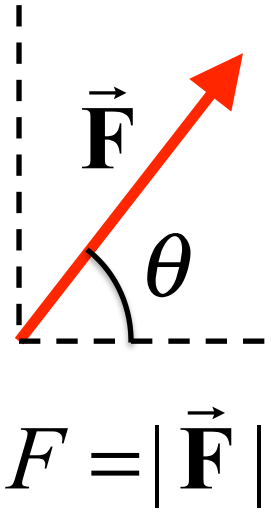
force

5 N ~ 1 lb

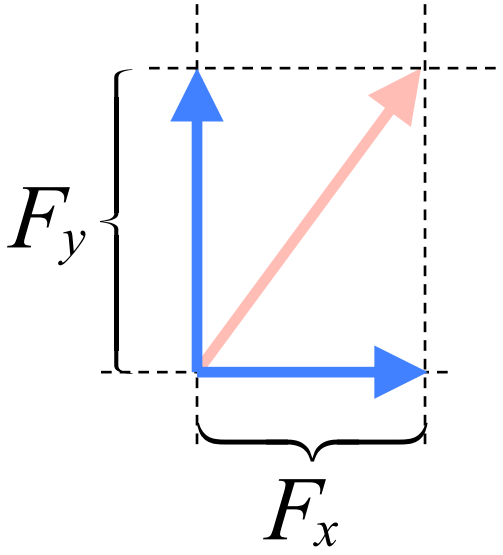
4.1 The Concepts of Force and Mass

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.



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



$$F_x = F\cos\theta$$
$$F_y = F\sin\theta$$

$$\theta = \tan^{-1}(F_y / F_x)$$
$$F = \sqrt{F_x^2 + F_y^2}$$

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

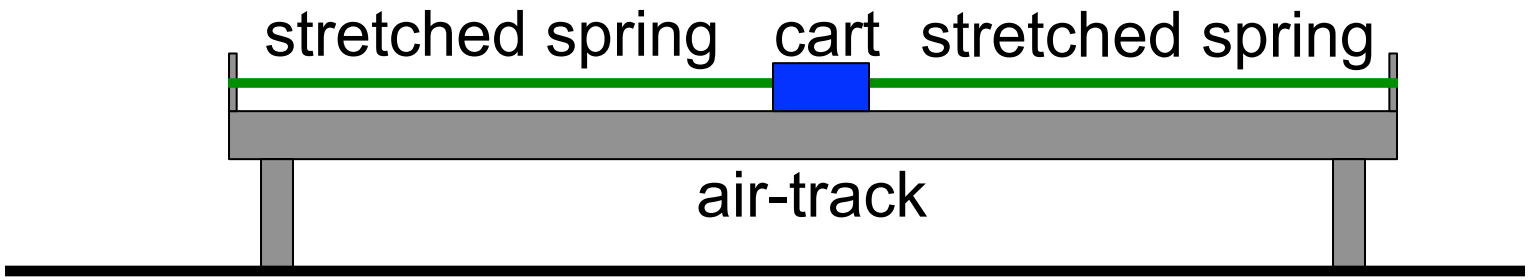
Mass can be measured without resorting to gravity/weight.

A spring will oscillate a mass with an oscillation period,

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

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

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

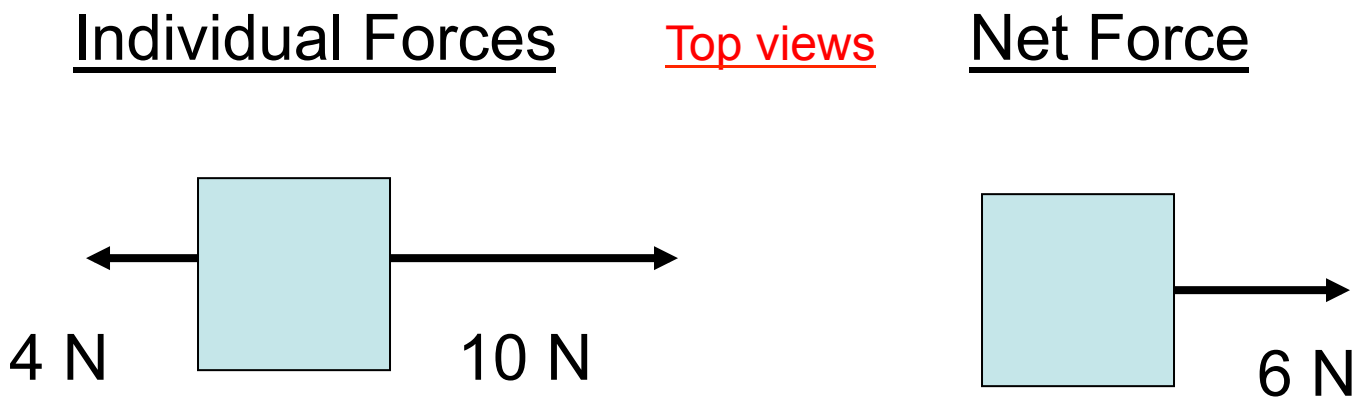
where the Greek letter sigma denotes the vector sum of all forces acting on an object.

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.

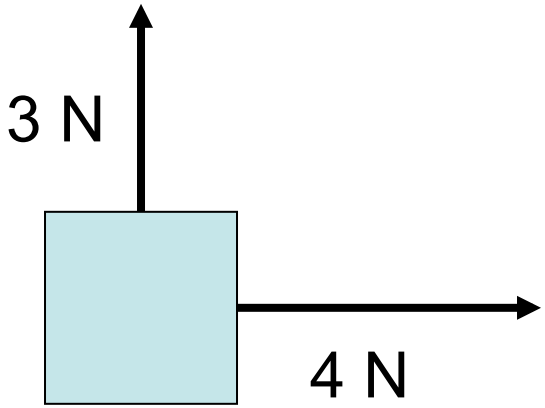
The SI unit of force is the Newton (N).



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

Individual Forces

Top view

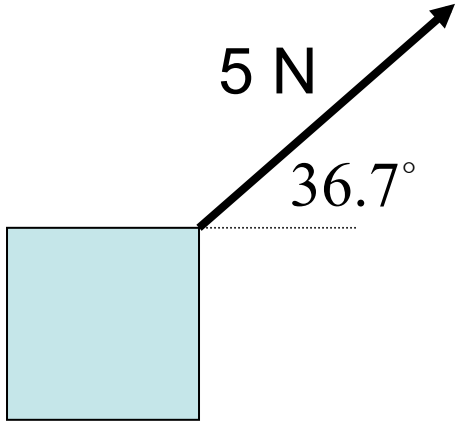


No friction

No Gravity

Net Force

Top view



θ is an angle with respect to x-axis

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

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

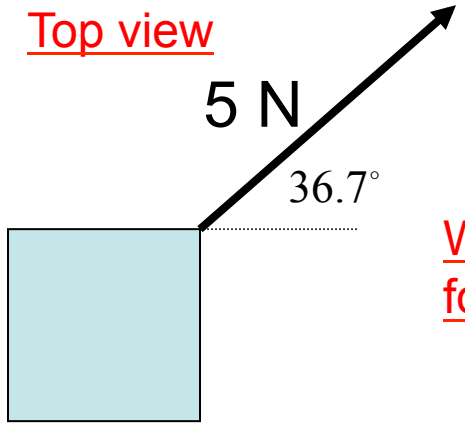
4.2 Newton's Laws of Motion (First Law)

Net Force

Top view

No friction

No Gravity

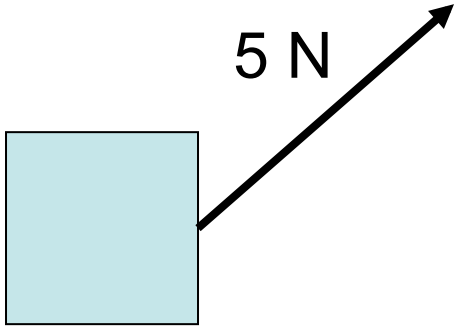


You will see this
in most textbooks.

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

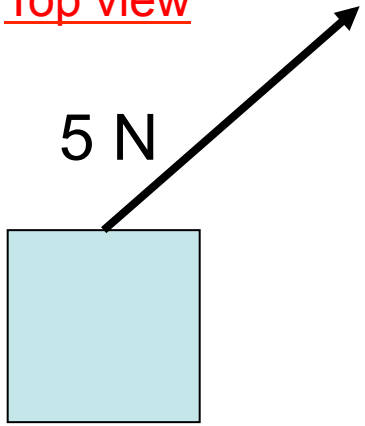
Why not

Top view



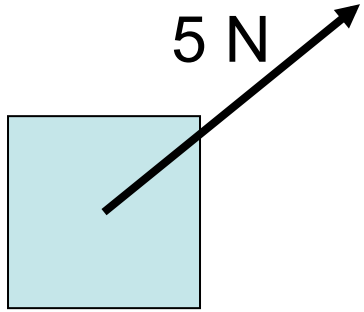
or this

Top view



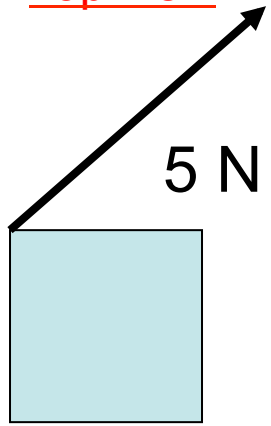
or this

Top view



or this

Top view

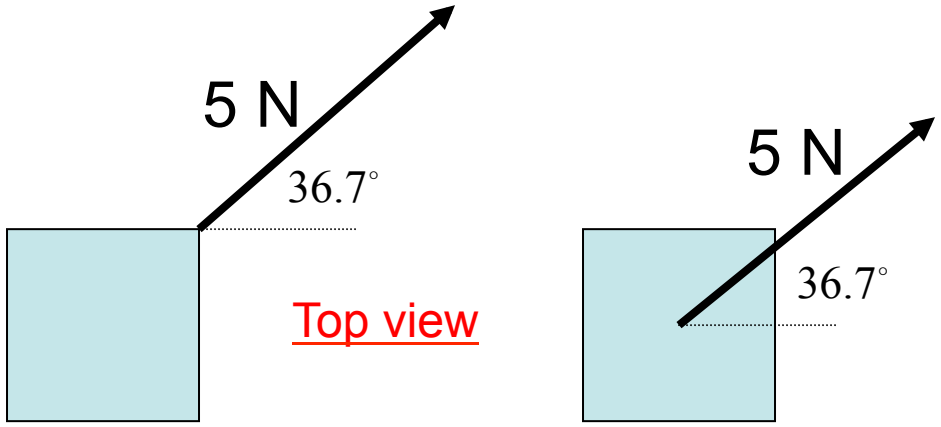


Best would be this,
attached to the center of object.

4.2 Newton's Laws of Motion (First Law)

No friction

No Gravity



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: $\vec{a}$

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 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.

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.

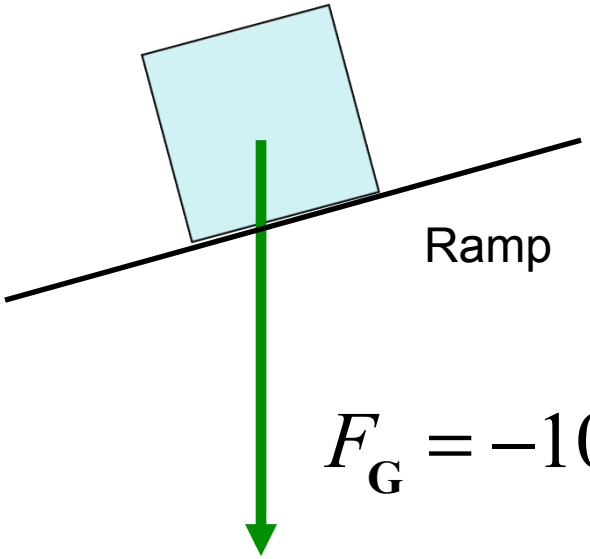
A mass at rest on a table.

A mass at rest on a ramp.

A mass sliding on a table.

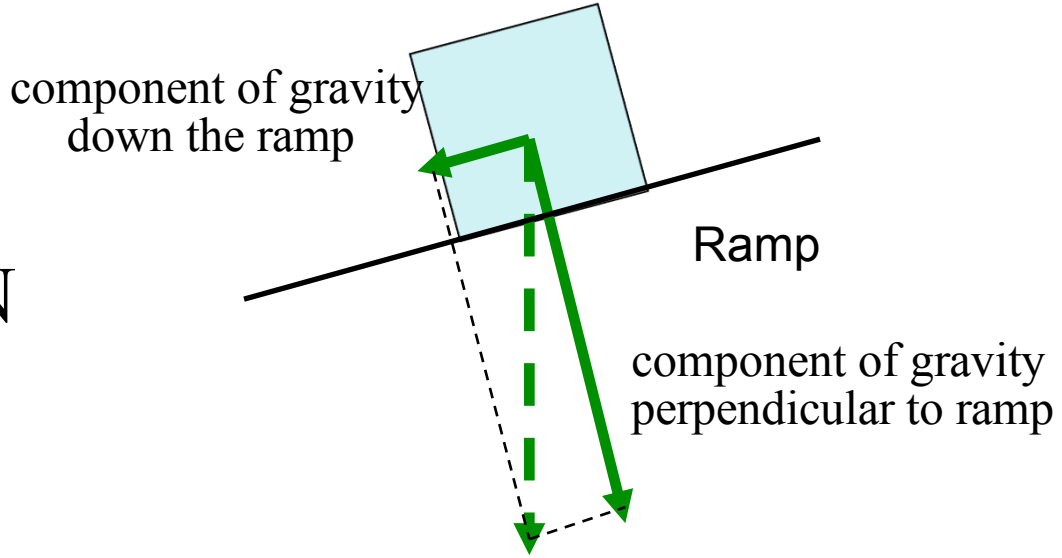
A mass at rest on a ramp.

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



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

Component of gravity pulls the mass down the the ramp



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