Summary of Chapters 1-3

Equations of motion for a uniformly acclerating object

Quiz to follow

An unbalanced force acting on an object results in its acceleration

Accelerated motion in time, t, described with equations using

- vectors: location ($\vec{\mathbf{x}}$), displacement ($\Delta\vec{\mathbf{x}}$), velocity ($\vec{\mathbf{v}}$), acceleration ($\vec{\mathbf{a}}$)
- scalars: length (ℓ), magitude($\vec{\mathbf{v}}$) = speed v, magnitude($\vec{\mathbf{a}}$) = a, angle (θ)

Vectors have a magnitude (positive scalar) and a direction.

- motion along a straight line (1D): direction is a sign (+ or –)
- motion in 2 dimensions (2D): direction is an angle θ

Components of 2D vector $\vec{\mathbf{A}}$, with magnitude A, angle θ wrt x-axis,

$$A_x = A\sin\theta, \text{ and } A_y = A\cos\theta \quad \Leftrightarrow \quad A = \sqrt{A_x^2 + A_y^2}, \text{ and } \theta = \tan^{-1}\left(A_y / A_x\right)$$

2D motion is much EASIER using components in each 1D direction.

Equations of 1D Kinematics

$$v = v_0 + at$$

$$x = \tfrac{1}{2}\left(v_0 + v\right)t$$

$$v^2 = v_0^2 + 2ax$$

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

Simplifications used

a) 1D vectors behave as scalars

direction is sign (+,–) of value

b) $x_0 = 0,\ \Delta x = x - x_0 \Rightarrow \Delta x = x$

displacement = location

c) $t_0 = 0,\ \Delta t = t - t_0 \Rightarrow \Delta t = t$

time interval = final time

Equations of 2D Kinematics

1D motion in x-direction

$$v_x = v_{0x} + a_x t$$

$$x = \tfrac{1}{2}\left(v_{0x} + v_x\right)t$$

$$v_x^2 = v_{0x}^2 + 2a_x x$$

$$x = v_{0x} t + \tfrac{1}{2}a_x t^2$$

1D motion in y-direction

$$v_y = v_{0y} + a_y t$$

$$y = \tfrac{1}{2}\left(v_{0y} + v_y\right)t$$

$$v_y^2 = v_{0y}^2 + 2a_y x$$

$$y = v_{0y} t + \tfrac{1}{2}a_y t^2$$

Objects in motion in the air, ignoring air friction effects, have a constant (–) acceleration in the vertical direction.

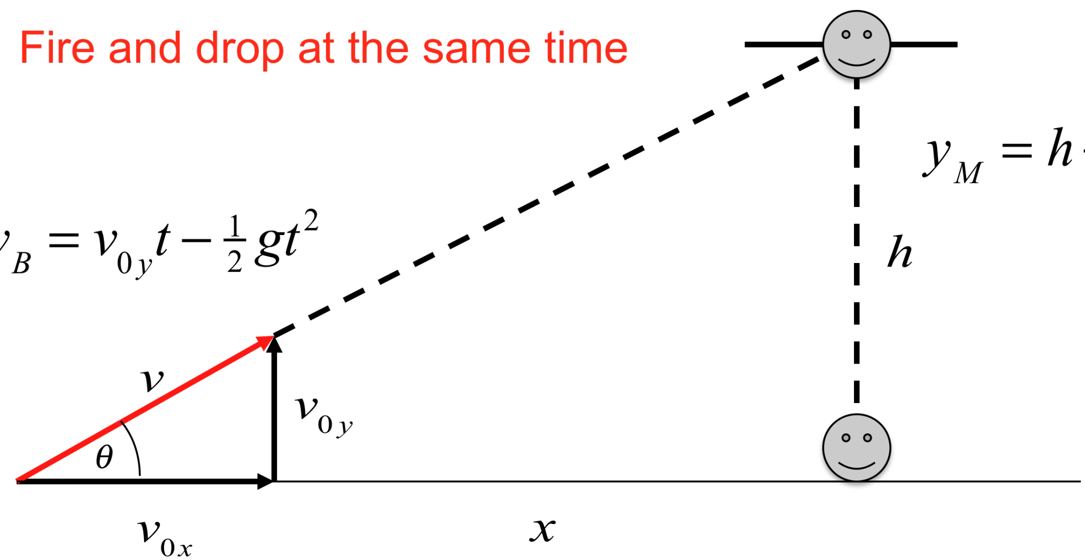
Defining up as positive, use: $a_y = -g = -9.80\ \text{m/s}^2, \quad a_x = 0$

Shoot the Monkey Demonstration

Fire and drop at the same time

$$y_B = v_{0y}t - \tfrac{1}{2}gt^2$$

$$y_M = h - \tfrac{1}{2}gt^2 \quad \text{(need } y_0 = h\text{, here)}$$



Shoot at the Monkey !

$$\frac{v_{0y}}{v_{0x}} = \frac{h}{x} = \tan\theta$$

Hit height: $y_B = y_M \quad \Rightarrow \quad v_{0y}t = h$

Hit time: $t = \dfrac{x}{v_{0x}}$ $\qquad \dfrac{v_{0y}}{v_{0x}}x = h$

Quiz 2

Chapter 4

Forces and Newton's Laws of Motion

4.1 *The Concepts of Force and Mass*

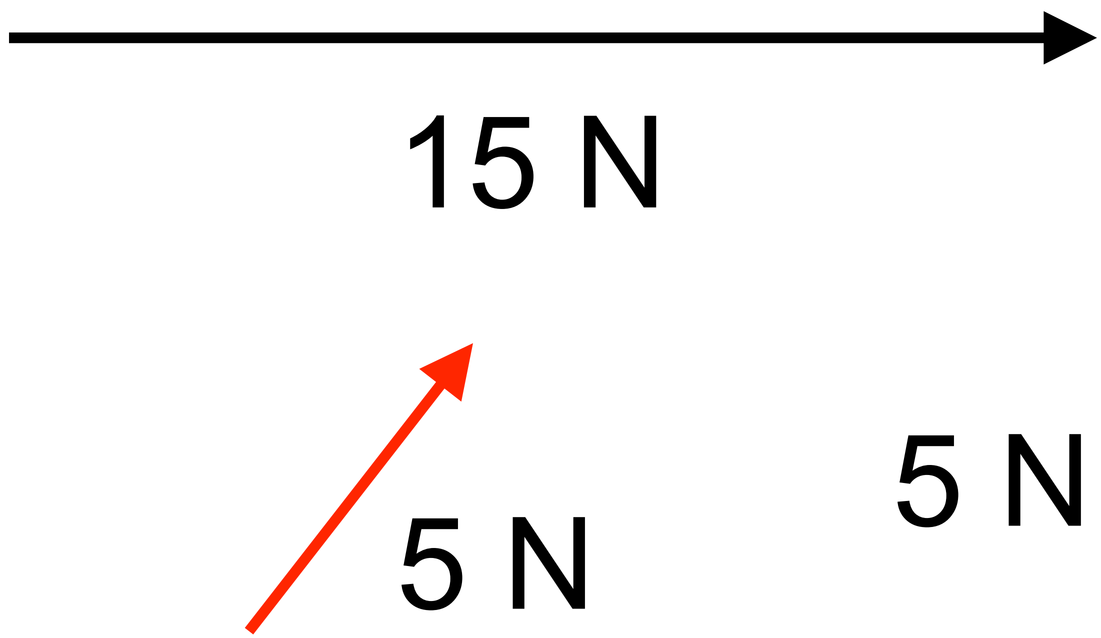
A ***force*** is a push or a pull acting on an object. A force is a vector!

Contact forces arise from physical contact, and are due to stretching or compressing at the point of contact.

Action-at-a-distance forces do not require contact and include gravity and electrical forces.

4.1 The Concepts of Force and Mass

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



5 N ~ 1 lb

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

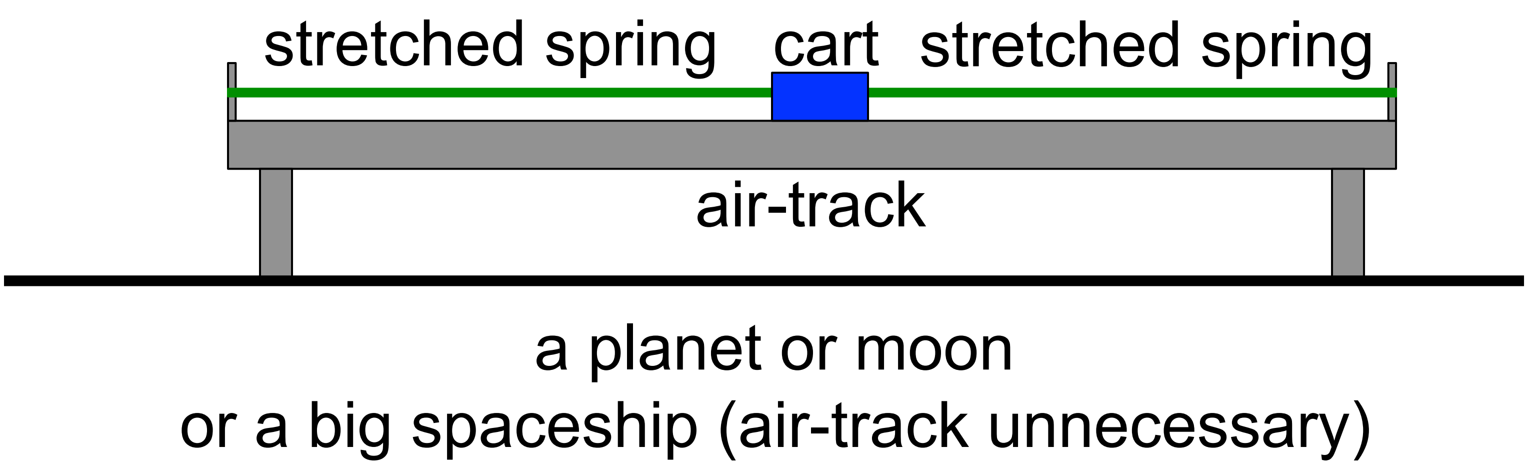
Mass **can be measured without resorting to gravity/weight.**

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



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.

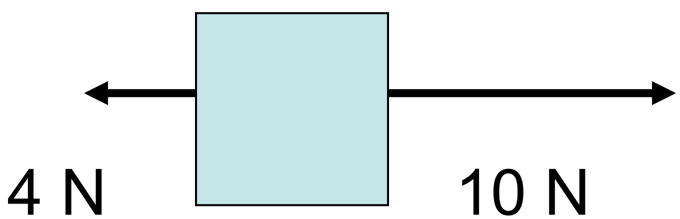
The *net force* is the vector sum of all of the forces acting on an object.

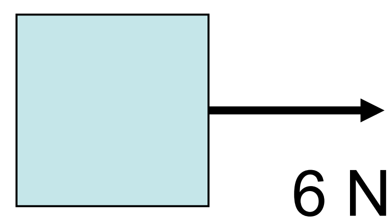
4.2 *Newton's First Law of Motion*

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

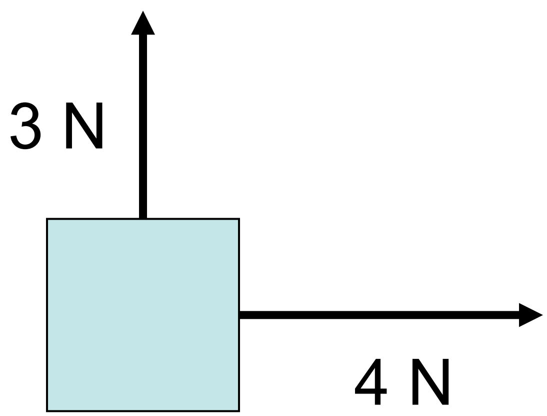




4.2 Newton's First Law of Motion

Individual Forces

Top view

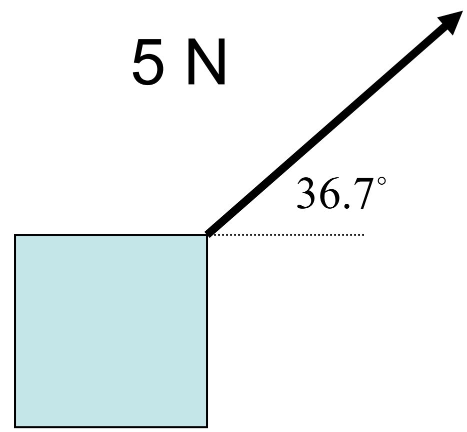


No friction

No Gravity

Net Force

Top view



θ is an angle with respect to x-axis

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

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

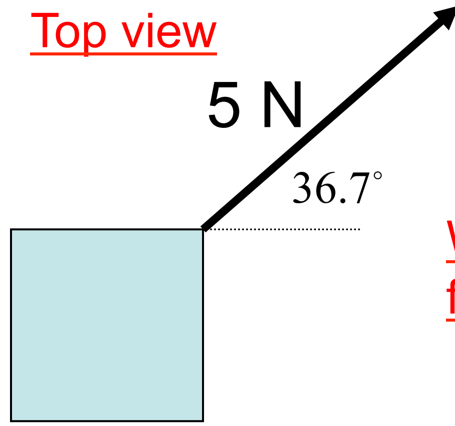
4.2 Newton's First Law of Motion

No friction

No Gravity

Net Force

Top view

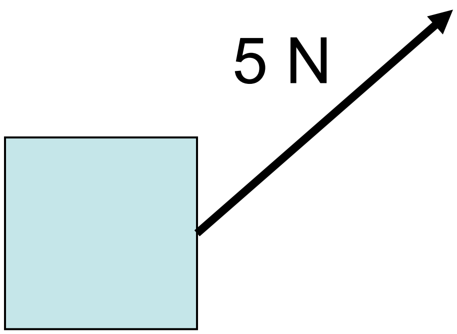


Why does the picture show the force vector attached to a corner ?

You will see this in most textbooks.

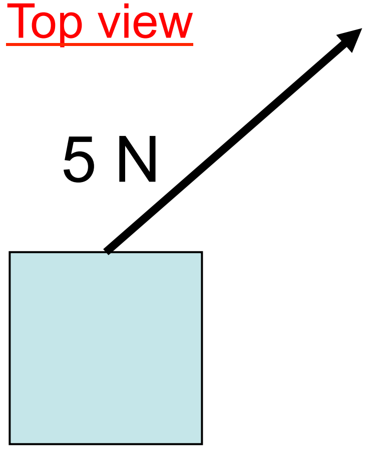
Why not

Top view



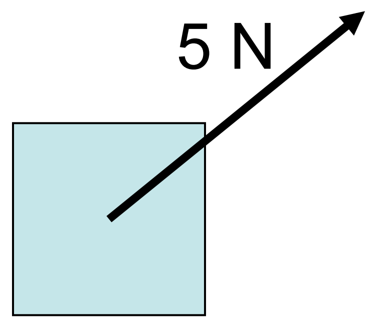
or this

Top view



or this

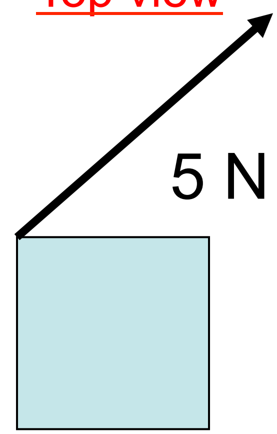
Top view



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

or this

Top view

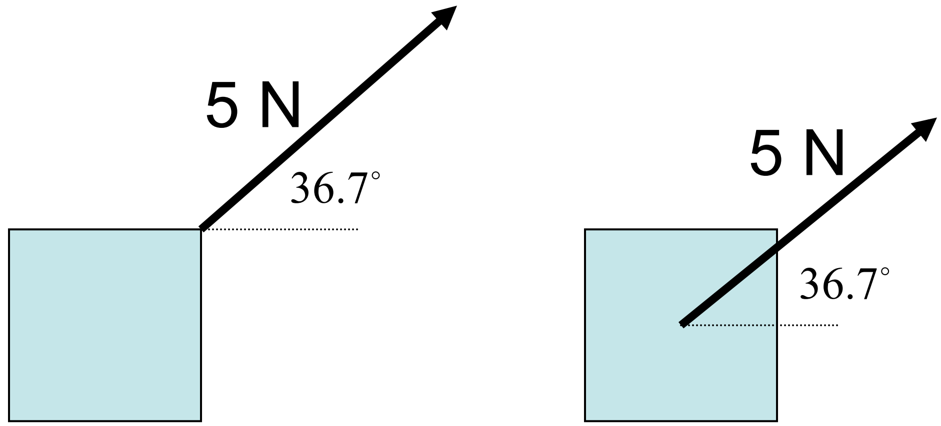


4.2 Newton's First Law of Motion

No friction

No Gravity

Top view

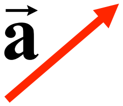


Both drawings lead to the same linear motion of the object

The object will not maintain a constant speed & direction.

velocity

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



4.2 Newton's First Law of Motion

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.

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.

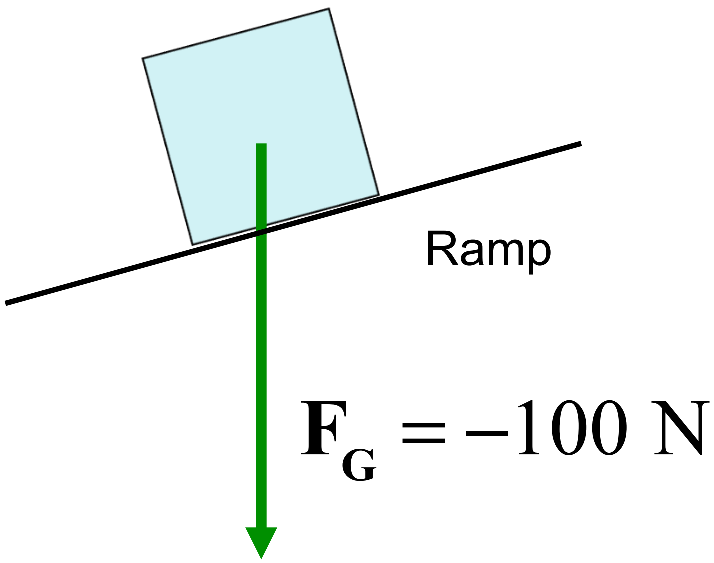
Newton's 1st law: for an object to *remain at rest*, or *move with constant speed & direction*, the Net Force acting on it must be ZERO.

Examples (4 clicker questions):

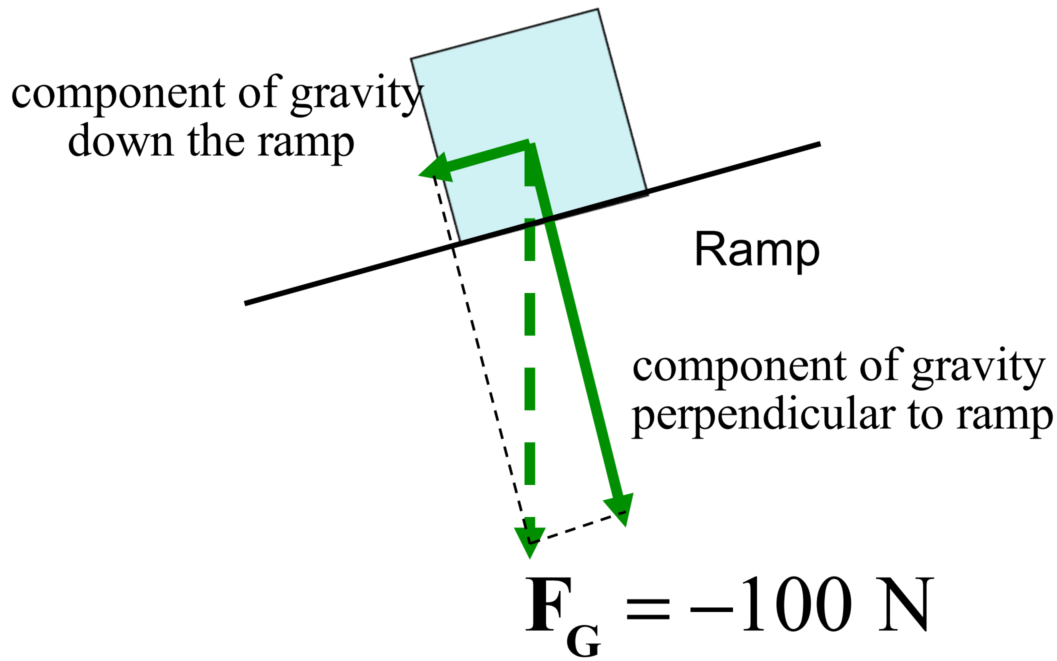
- A mass hanging from a string.
- A mass at rest on a table.
- A mass at rest on a ramp.
- A mass sliding on a table.

A mass at rest on a ramp.

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



Component of gravity pulls the mass down the the ramp



Mathematically, the net force is written as

$$\sum \vec{\mathbf{F}}$$

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

Newton's Second Law

When a net external force acts on an object of mass *m*, the acceleration that results is directly proportional to the net force and has a magnitude that is inversely proportional to the mass. The direction of the acceleration is the same as the direction of the net force.

$$\vec{\mathbf{a}} = \frac{\sum \vec{\mathbf{F}}}{m} \qquad \sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$$

SI Unit for Force

$$(\mathrm{kg})\left(\frac{\mathrm{m}}{\mathrm{s}^2}\right) = \frac{\mathrm{kg}\cdot\mathrm{m}}{\mathrm{s}^2}$$

Note: it has the same units as ma.

This combination of units is called a *newton* (N).

$$1\,\mathrm{kg}\cdot\mathrm{m/s}^2 = 1\,\mathrm{N}$$

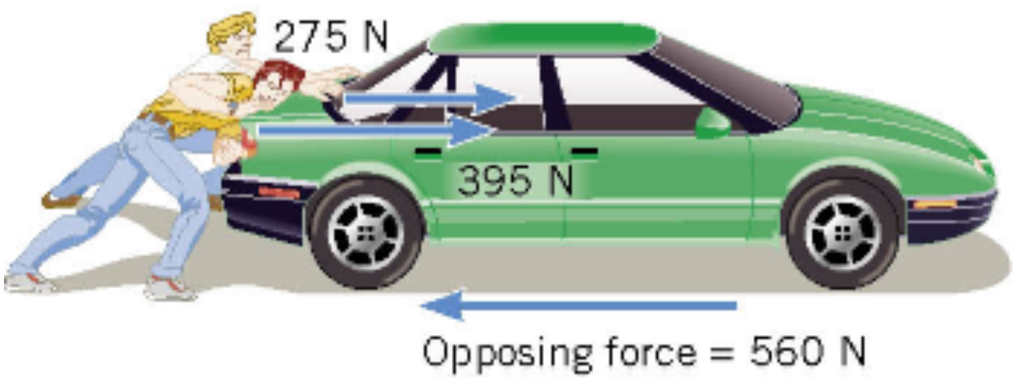
4.3 Newton's Second Law of Motion

Table 4.1 Units for Mass, Acceleration, and Force

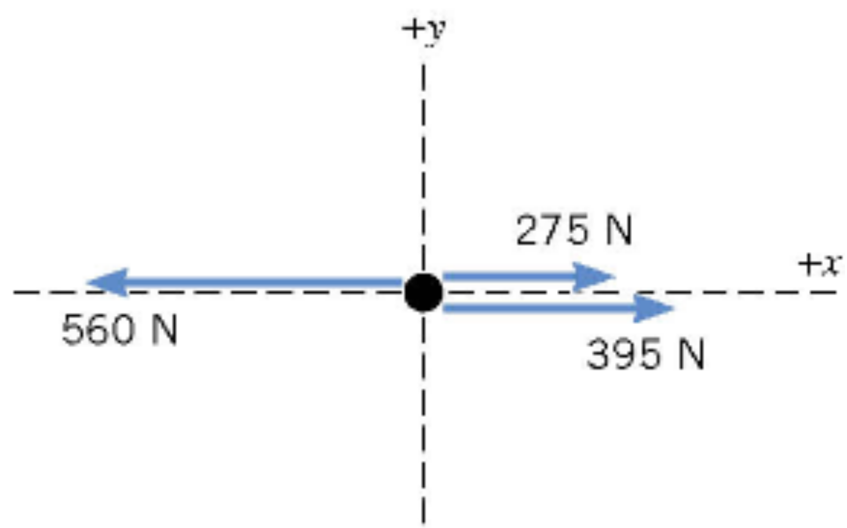
System	Mass	Acceleration	Force
SI	kilogram (kg)	meter/second^2 (m/s^2)	newton (N)
CGS	gram (g)	centimeter/second^2 (cm/s^2)	dyne (dyn)
BE	slug (sl)	foot/second^2 (ft/s^2)	pound (lb)

$\sim 5\,\text{N} = 1\,\text{lb}$

A ***free-body-diagram*** is a diagram that represents the object and the forces that act on it.

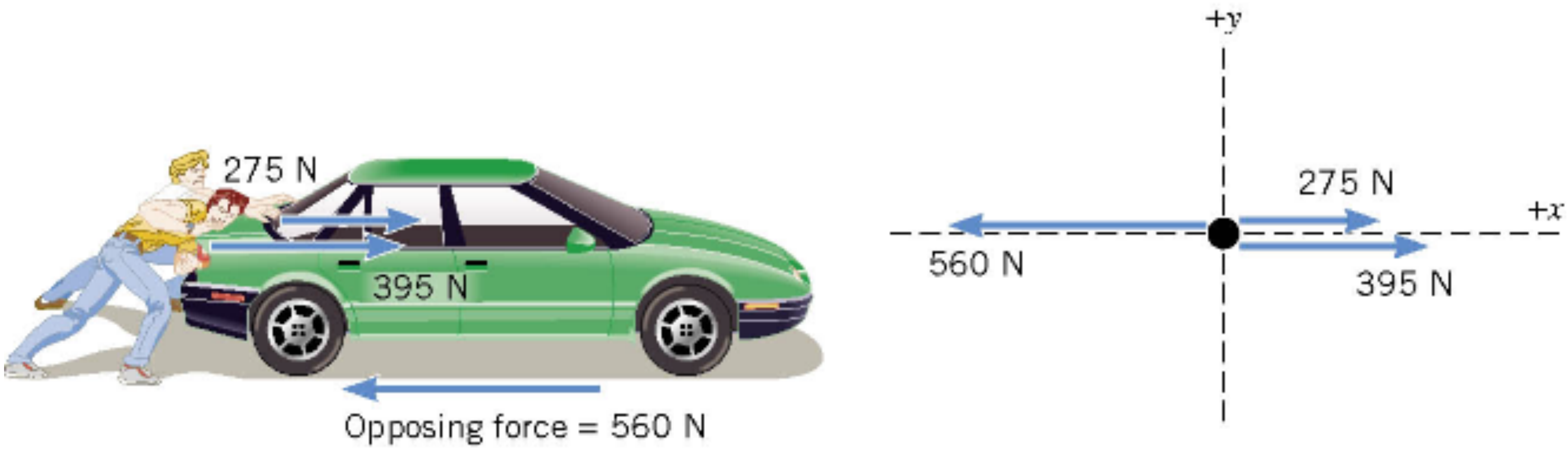


(a)



(b) Free-body diagram of the car

4.3 Newton's Second Law of Motion



(*a*) (*b*) Free-body diagram of the car

The net force in this case is:

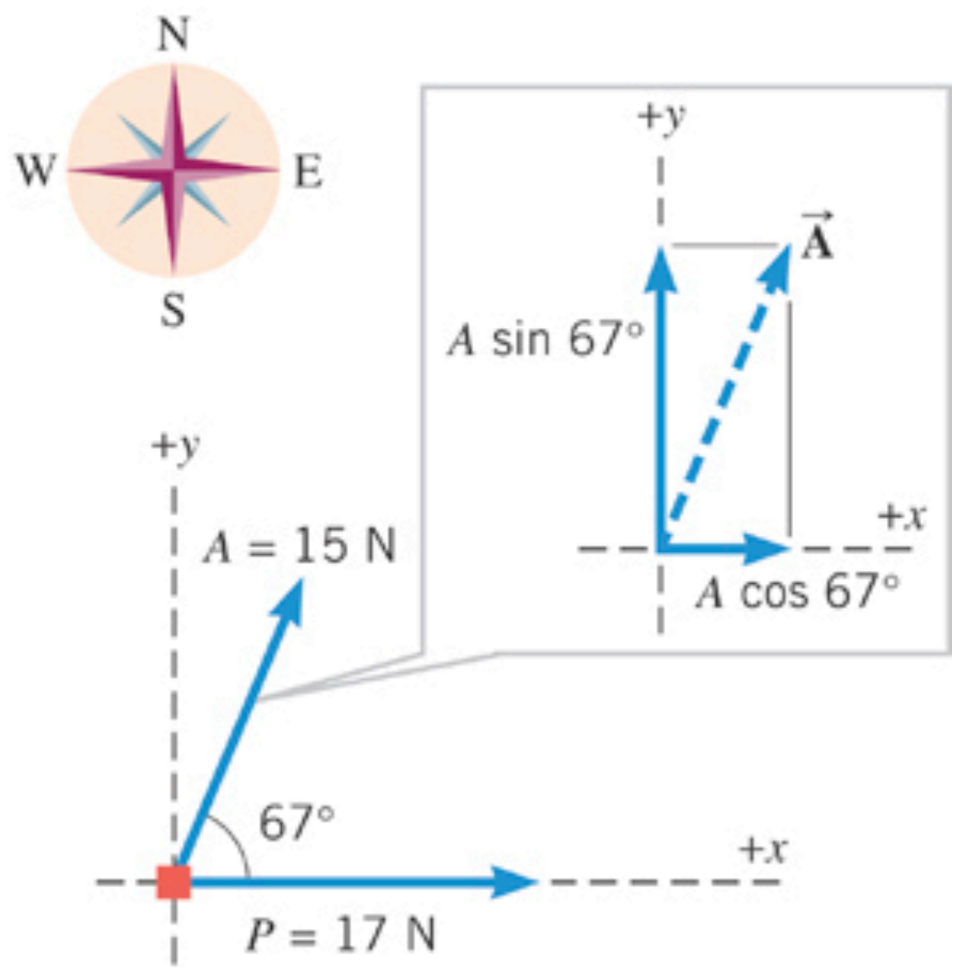
275 N + 395 N – 560 N = +110 N

and is directed along the + x axis of the coordinate system.

If the mass of the car is 1850 kg then, by Newton's second law, the acceleration is

$$a = \frac{\sum F}{m} = \frac{+110\,\mathrm{N}}{1850\,\mathrm{kg}} = +0.059\,\mathrm{m/s^2}$$

Next Lecture: Net force when individual forces are not acting along a straight line.



Free-body diagram of the raft