Newton's Second Law of Motion

by

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P3.4 Forces and Acceleration

The change of speed and/or direction (acceleration) of an object is proportional to the net force and inversely proportional to the mass of the object. The acceleration and net force are always in the same direction.

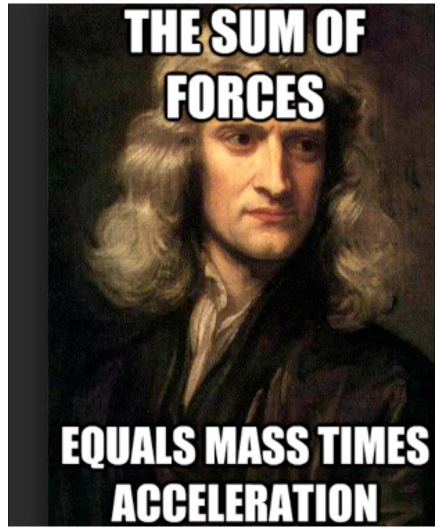
P3.4A Predict the change in motion of an object acted on by several forces.

P3.4C Solve problems involving force, mass,

Items:

1. Newton's Second Law of Motion.

2. Net Force, Acceleration.



Isaac Newton

English scientist (1642-1727)

He came up with three laws of motion which form the basis of (classical) mechanics. They described the effects of forces on objects with masses. Newton's Laws of Motion apply universally, from the motion of galaxies to the motion of subatomic particles.

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 inversely proportional to the mass.

Acceleration = Net Force / Mass

The direction of the acceleration is the same as the direction of the net force.

The acceleration of an object increases when the net external force increases.

The acceleration decreases when the mass of the object increases.

F net: It is the sum of all the external forces acting on the object in Newton (N):

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

Newton's Second Law of Motions

Net Force = Mass x Acceleration

$$\vec{F}_{net} = m \times \vec{a}$$

Rearrange:

Acceleration = Net Force / Mass

($a = F\ net / m$)

Mass = Net Force / Acceleration

($m = F\ net / a$)

m: Mass in kilogram (kg).

a: Acceleration in m/s^2 . Near the Earth's surface, acceleration due to gravity is approximately constant and has a value of a = ***g*** **= 9.8** $\mathbf{m/s^2}$**)**

Example 1:

What is the acceleration of a 70 kg skater, acted upon an unbalanced force of 161 N[W]?

Data Table		
$Fnet$	m	a
161 N [W]	70 kg	?

According to Newton's Second Law of Motion:

$$F\,net = m \times a$$

or

$$a = F\,net / m$$

Acceleration = net Force/ Mass = 161 / 70 = 2.3 m/s^2 [W]

Net Force Calculation

When opposing forces (forces of opposite directions) act on an object, the net force can be calculated using the following 3 steps:

Step One: Add all the forces in the same direction.

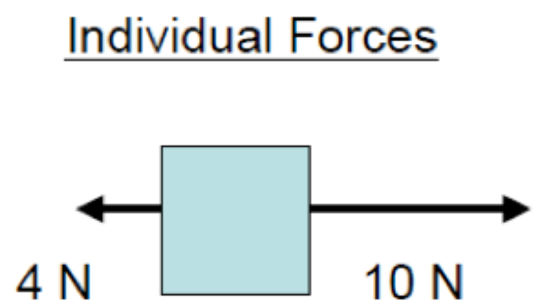
Step Two: Choose a positive direction. Then, the opposite direction would be the negative direction.

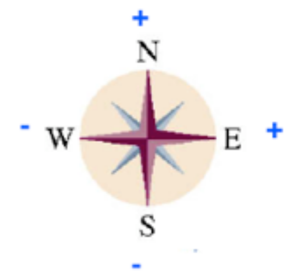
Step Three: Calculate the net force by adding all the forces in the different directions, as shown in the formula below:

Net Force = forces in the positive direction + forces in the negative direction

Example 2:

This is an example of individual forces of opposite direction acting on an object.





1. What is the net force?

2. Does the object move forward or backward?

Follow the steps in page 4 to solve the problem.

1) Add all the forces in the same direction

There are two forces acting on this object:

One is 10 N pushing the object forward to the right.

The other force is 4 N pulling the object back to the left.

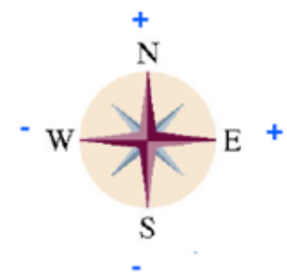
2) Choose a positive direction. Then, the opposite direction would be the negative direction.

Assume that the east forward direction is the positive direction.

So, F = + 10 N

So, the west backward direction is the negative direction.

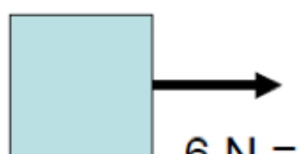
So, F = - 4 N



3) Net Force = Add all the forces in opposing directions.

The net force = 10 N - 4 N = 6 N.

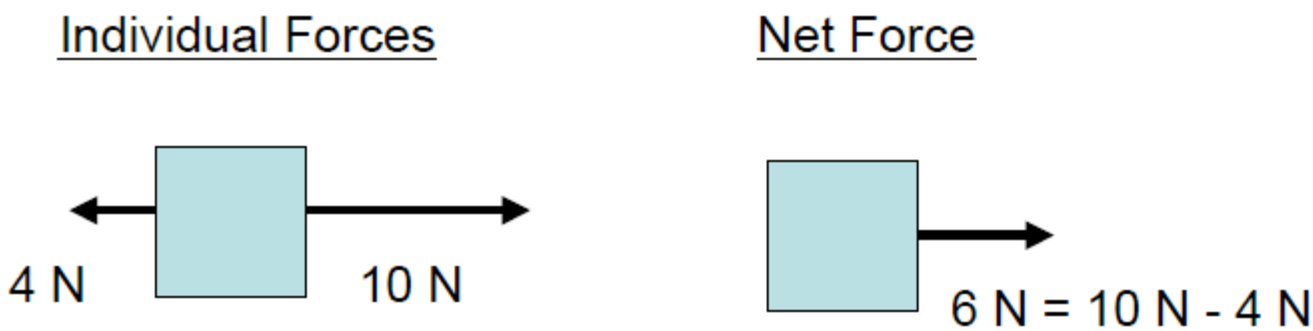
Net Force



6 N = 10 N - 4 N

The net force is positive, so the object moves forward toward the east.

This is a summary of the sample problem.



There is a net force of 6 N pushing the object forward to the east.

A Mathematical Symbol of the Net Force

Mathematically, the net force is written as:

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

where the Greek letter sigma ($\sum$)denotes the vector sum.

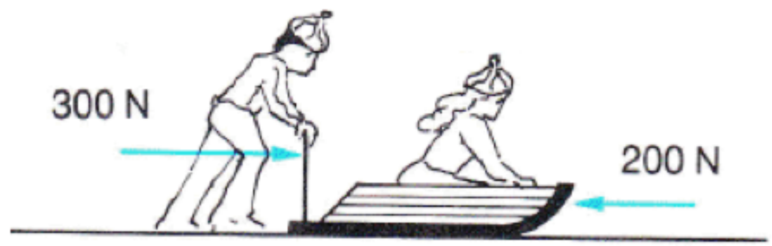
Free-body-diagram

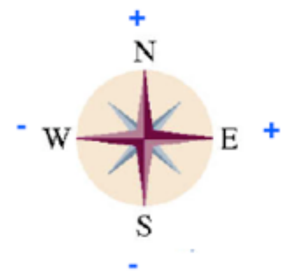
A free-body diagram will help when solving problems using Newton's Second Law of motion and to determine the net force (F net).

A *free-body-diagram* is a diagram that represents the object and the forces that act on it. Below is how to use the free-body diagram to solve the problem.

Example 3: *A Boy Giving a Ride*

A boy gives his sister a ride on a sled by exerting a force of 300 N [east]. Frictional resistance exert a force of 200 N [west]. The sister and the sled have a combined mass of 50 kg.





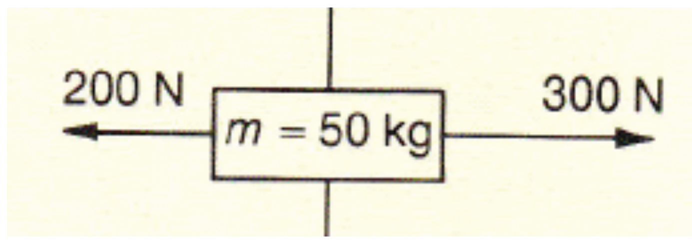
a) Find the net force. Assume that the east direction is positive.

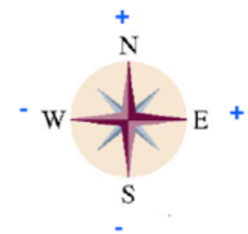
b) Find the sled's acceleration.

Data Table				
$F_{[East\ direction]}$	$F_{[west\ direction]}$	m	a	$Fnet$
300 kg	- 200 kg	50 kg	?	?

Solution:

This is the *free-body-diagram* and represents the girl and the sled and the forces that act on them. They both have a mass of 50 kg.





Below is how to use the free-body diagram to solve the problem.

a) F net = sum of all the forces acting on the girl and the sled

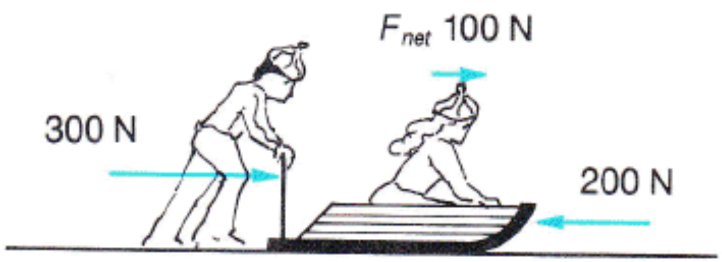
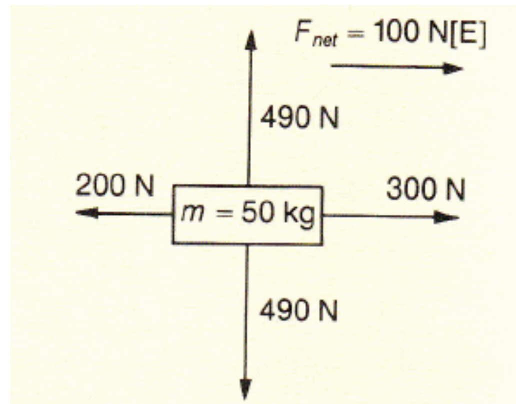
= force of the boy + frictional forces

= 300 N - 200 N

= 100 N [east]

So a net force of 100 N is pushing the sled forward toward the east direction.

So the problem can be represented like this:

Sketch	Free-body diagram
	

Note:

The weight of the girl of the sled = 50 x 9.8 = 490 N and is directed toward the center of the earth (downward). It is canceled by the normal force (support force) in the opposite direction (upward) exerted by the earth on the sled and girl.

b) According to Newton's Second Law of Motion;

Acceleration = Net Force / Mass

$$\vec{a} = \vec{F}_{net} / m$$

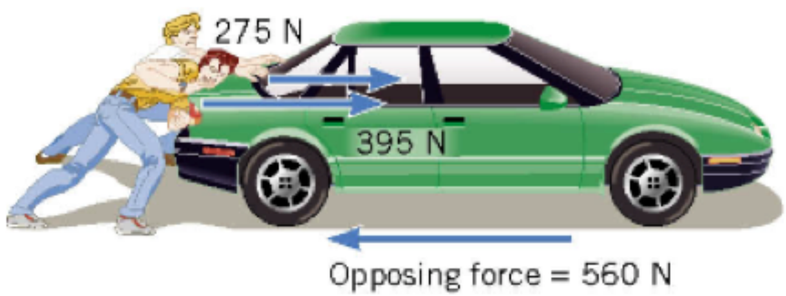
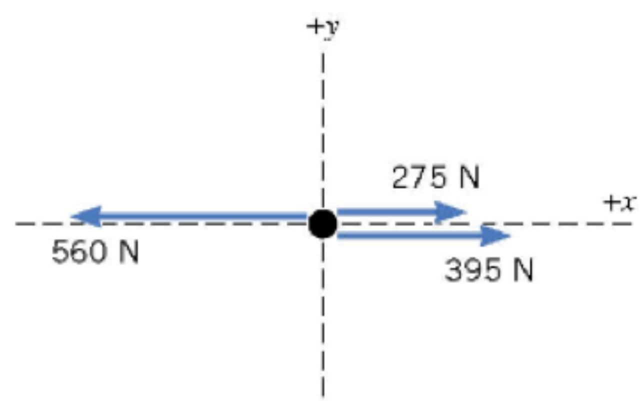
$$= 100 / 50$$

$$= 2.0 \text{ m/s}^2$$

The sled accelerates at 2.0 m/s^2 [east]. The sled moved forward.

Example 4: *Two people push a stalled car in opposition to a force created by friction and the pavement.*

Two people are pushing a stalled car, as shown below. One person pushes with a force of 275 N. The other pushes with a force of 395 N. A third force of 560 N in the opposing direction is the friction and the pavement.

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

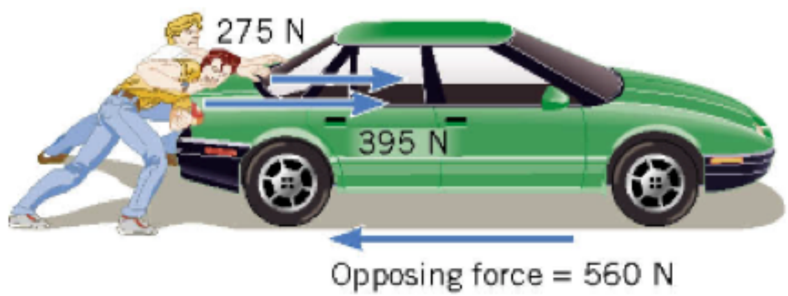
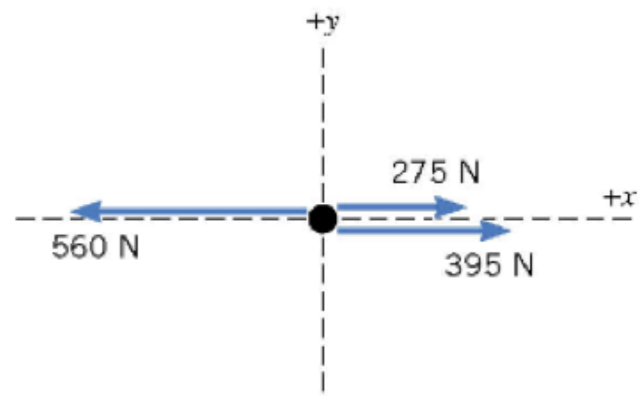
Sketch	Free-body diagram
 (a)	 (b) Free-body diagram of the car

Figure (a): two people push a stalled car, in opposition to a force created by friction and the pavement.

Figure (b): a free-body diagram that shows the horizontal forces acting on the car. In the diagram, the car is represented as a black dot, and its motion is along the +x axis. The free - body diagram is very helpful when applying Newton's second law and to determine the net force (F net).

References:

1) Humanic. (2013). www.physics.ohio-state.edu/~humanic/. In Thomas Humanic Brochure Page.

Physics 1200 Lecture Slides: Dr. Thomas Humanic, Professor of Physics, Ohio State University, *2013-2014 and Current. www.physics.ohio-state.edu/~humanic/*

2) Cutnell, J. D. & Johnson, K. W. (1998). *Cutnell & Johnson Physics, Fourth Edition*. New York: John Wiley & Sons, Inc.

The edition was dedicated to the memory of Stella Kupferberg, Director of the Photo Department: "We miss you, Stella, and shall always remember that a well-chosen photograph should speak for itself, without the need for a lengthy explanation"

3) Martindale, D. G. & Heath, R. W. & Konrad, W. W. & Macnaughton, R. R. & Carle, M. A. (1992). *Heath Physics.* Lexington: D.C. Heath and Company

4) Zitzewitz, P. W. (1999). *Glencoe Physics Principles and Problems*. New York: McGraw-Hill Companies, Inc.

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