Introduction to Physical Science

Newton's Laws of Motion and Gravity

Presented by Robert Wagner

Force

- A force is a push or pull
  - It is a vector quantity so it has both magnitude and direction
- Free-body diagram
  - Illustrates all external forces on an object

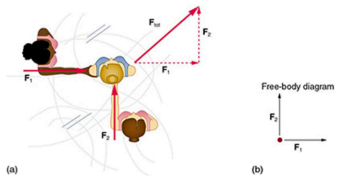

Figure 4.3 Part (a) shows an overhead view of two ice skaters pushing on a third. Forces are vectors and add like other vectors, so the total force on the third skater is in the direction shown. In part (b), we see a free-body diagram representing the forces acting on the third skater.

Image Credit: OpenStax College Physics - Figure 4.3

Newton's First Law of Motion

- A body at rest remains at rest, or, if in motion, remains in motion at a constant velocity unless acted on by a net external force
  - Everyday experience - object slow down due to friction or air resistance
  - Consider an air hockey table
  - Law is universal and applies to everything
  - Any change in velocity (speed or direction) requires an external force (planetary orbits)
- Mass - The amount of matter in an object
  - Differs from weight - does not depend on location
  - This law introduces the concept of inertia
  - Which has more mass - A kilogram of cotton balls or a kilogram of gold?

Newton's Second Law of Motion

- Relates force to change in motion
- Need to consider external forces
- The net force is what causes a change in motion
  - A free-body diagram helps us keep track of the forces

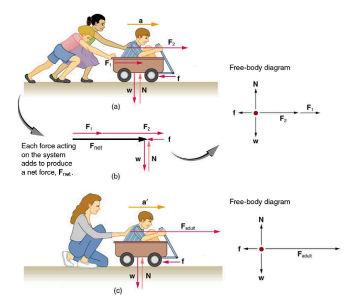

Image credit: OpenStax College Physics - Figure 4.5

Newton's Second Law of Motion

- A larger force will give a larger change in motion
  -
- A larger mass will have a smaller change in motion
  -
- Newton's Second law:
  - or,

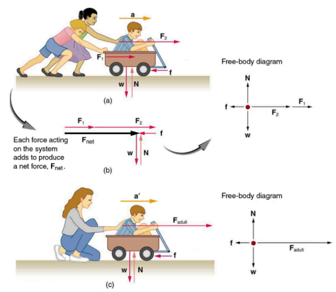

Image credit: OpenStax College Physics - Figure 4.5

Units for Force

- SI unit for force - Newton (N)
  - 1 Newton is the force needed to accelerate a 1 kg object at 1 m/s^2
  - 1 N = 1 kg m/s^2

Weight and Gravitational Force

- The net force on a falling object is the gravitational force
  - The acceleration due to gravity is g (9.80 m/s^2)
  - Weight (w) = mg
  - The weight is the force with which Earth pulls on an object
  - So, w=mg = (1.0 kg) (9.80 m/s^2) = 9.8 N

Free-Fall

- What do we mean by "weightlessness" in space
  - The gravitational force and acceleration are not much lower at the International Space Station than on Earth
  - Astronauts are falling continually which makes them appear weightless
- Mass and Weight
  - These are two different concepts in physics
  - Mass - the amount of matter contained in an object
  - Weight - measure fo the force of gravity pulling on an object

Example

- The net external force exerted on a lawnmower is 51 N. The mass of the mower is 24 kg. What is the acceleration?
  - Draw a sketch
  - List known values ; identify unknown
  - Determine equation to use
  - Plug in known values and solve

Figure 4.7 The net force on a lawn mower is 51 N to the right. At what rate does the lawn mower accelerate to the right?

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$F_{net} = 51\ N\ ;\ m = 24\ kg$

Unknown: acceleration (a)

$$a = \frac{F_{net}}{m}$$

$$a = \frac{51\ N}{24\ kg} = \frac{51 kg\ m/s^2}{24\ kg}$$

$$a = 2.1 m/s^2$$

Newton's Third Law of Motion

- Whenever one body exerts a force on a second body, the first body experiences a force that is equal in magnitude and opposite in direction to the force it exerts
- Forces will always occur in pairs
  - Force of the feet on wall is equal and opposite to the force of the wall on the feet
  - Our system of interest is only looking at the one force

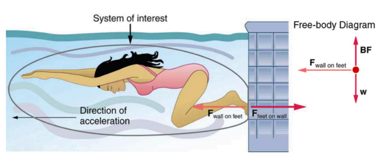
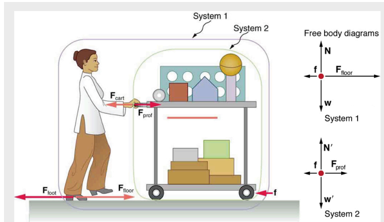


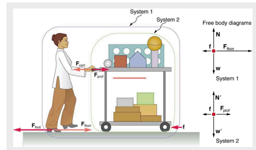
Figure 4.9 When the swimmer exerts a force $\mathbf{F}_{feet\ on\ wall}$ on the wall, she accelerates in the direction opposite to that of her push. This means the net external force on her is in the direction opposite to $\mathbf{F}_{feet\ on\ wall}$. This opposition occurs because, in accordance with Newton's third law of motion, the wall exerts a force $\mathbf{F}_{wall\ on\ feet}$ on her, equal in magnitude but in the direction opposite to the one she exerts on it. The line around the swimmer indicates the system of interest. Note that $\mathbf{F}_{feet\ on\ wall}$ does not act on this system (the swimmer) and, thus, does not cancel $\mathbf{F}_{wall\ on\ feet}$. Thus the free-body diagram shows only $\mathbf{F}_{wall\ on\ feet}$, $\mathbf{w}$, the gravitational force, and $\mathbf{BF}$, the buoyant force of the water supporting the swimmer's weight. The vertical forces $\mathbf{w}$ and $\mathbf{BF}$ cancel since there is no vertical motion.

Example

- Professor pushes a cart. Her mass is 65.0 kg, the cart's mass is 12.0 kg and the equipment is 7.0 kg. Calculate the acceleration produced when the professor exerts a backward force of 150 N on the floor. Opposing forces, including friction total 24.0 N
  - Draw a sketch
  - List known values ; identify unknown
  - Determine equation to use
  - Plug in known values and solve



Example



- Professor pushes a cart. Her mass is 65.0 kg, the cart's mass is 12.0 kg and the equipment is 7.0 kg. Calculate the acceleration produced when the professor exerts a backward force of 150 N on the floor. Opposing forces, including friction total 24.0 N. (System 1)
  - Draw a sketch
  - List known values ; identify unknown
  - Determine equation to use
  - Plug in known values and solve

$F_{floor} = 150\,N\,;\; f = 24.0\,N\,;\; m_{prof} = 65.0\,kg$

$m_{cart} = 12.0\,kg\,;\; m_{equipment} = 7.0\,kg$

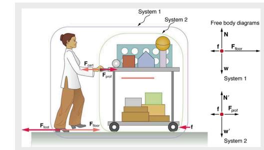
$$a = \frac{F_{net}}{m}$$

$F_{net} = F_{floor} - f = 150\,N - 24.0\,N = 126\,N$

$m = 65.0\,kg + 12.0\,kg + 7.0\,kg = 84\,kg$

$$a = \frac{126\,N}{84\,kg} = 1.5 m/s^2$$

Example



- Professor pushes a cart. Her mass is 65.0 kg, the cart's mass is 12.0 kg and the equipment is 7.0 kg. Calculate the force the professor exerts on the cart. (System 2)
  - Draw a sketch
  - List known values ; identify unknown
  - Determine equation to use
  - Plug in known values and solve

$F_{floor} = 150\,N\,;\; f = 24.0\,N\,;\; m_{prof} = 65.0\,kg$

$m_{cart} = 12.0\,kg\,;\; m_{equipment} = 7.0\,kg$

$F_{net} = F_{prof} - f\,;\; F_{prof} = F_{net} + f$

$m = 12.0\,kg + 7.0\,kg = 19.0\,kg$

$F_{net} = ma = (19.0\,kg)(1.5\,m/s^2) = 29\,N$

$F_{prof} = F_{net} + f = 29\,N + 24.0\,N = 53\,N$

Universal Law of Gravitation

- Could the orbit of our Moon be related to a falling apple?
  - Gravity of Earth extends out into space
- Every particle in the universe attracts every other particle with a force along a line joining them
  - Forces between two objects are always equal and opposite
  - Force of Earth on Moon is equal in magnitude and opposite in direction to the force of our Moon on Earth

Figure 6.20 According to early accounts,

Universal Law of Gravitation

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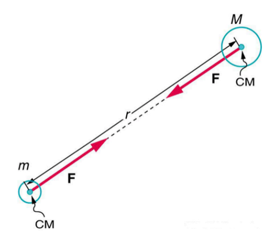


Figure 6.21 Gravitational attraction is along a line joining the centers of mass of these two bodies. The magnitude of the force is the same on each, consistent with Newton's third law.

Universal Law of Gravitation

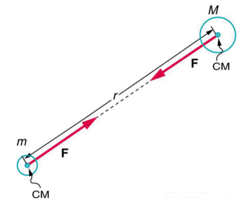
- Force is given by:
  -
  - G is the gravitational constant:
  - Gravitational force is a relatively weak force compared to other forces of nature

Example

- Calculate the gravitational force between Earth and our Moon. Use

  ; ;

  - Draw a sketch
  - List known values ; identify unknown
  - Determine equation to use
  - Plug in known values and solve



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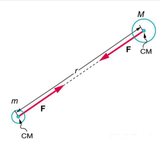
Example



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- Calculate the gravitational force between Earth and our Moon. Use

  ; ;

  - Draw a sketch
  - List known values ; identify unknown
  - Determine equation to use
  - Plug in known values and solve

$M_{Earth} = 5.98x10^{24}\ kg$;
$m_{Moon} = 7.35x10^{22}\ kg$;
$Radius\ of\ Moon's\ orbit = 3.84x10^{8}\ m$

$$F = \frac{GMm}{r^2}$$

$$F = 6.67x10^{-11} \frac{Nm^2}{kg^2} \frac{(5.98x10^{24}\ kg)(7.35x10^{22}\ kg)}{(3.84x10^{8}\ m)^2}$$

$$F = 1.99x10^{20}\ N$$

Summary

- Newton's laws of motion are universal and apply to all objects
- Weight is measured in the SI unit of Newton and is very different than mass
- Newton's Universal Law of Gravitation is universal and describes the force between any two objects with mass in the universe