Physics 23 Chapter 4 Part One

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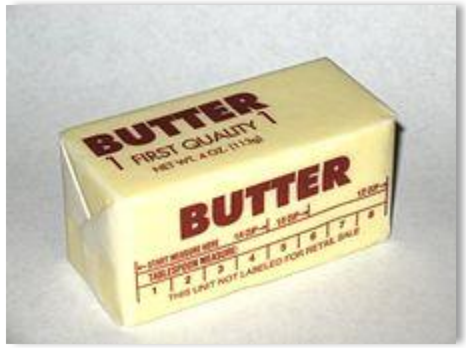
Video Lecture 1: Newton's Second Law
Video Lecture 2: The Gravitational Force
Video Lecture 3: Gravitational Force Problem

Mass, Force, Newton's Laws

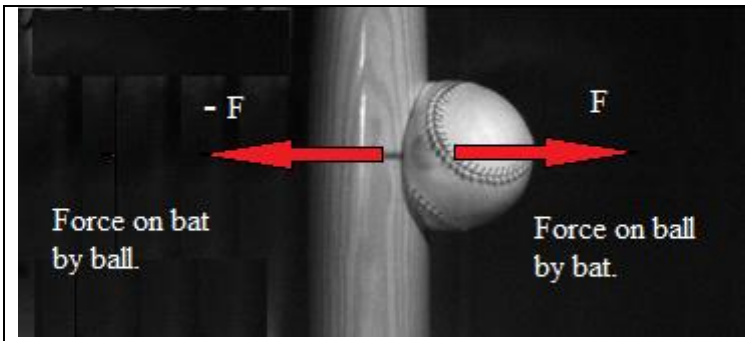
The mass of an object is a measure of how hard it is to accelerate it. The greater the mass, the harder it is to make it move if it was initially stationary, and the harder it is to slow it down or speed it up if it's already moving. Another name for mass is "linear inertia," a quantity we won't mention again until Chapter 8. The standard international (SI) units for mass is the kilogram (kg). 1000 grams = 1 kilogram <u>Mass Examples:</u> -One "classic" M&M Candy: one gram -A penny has a mass of about three grams. -Average body mass globally is 62 kg.	A $20 bill has a mass of about one gram.  One kilogram of *any* substance—solid, liquid, or gas— has a weight of about 2.2 lbs.

Force

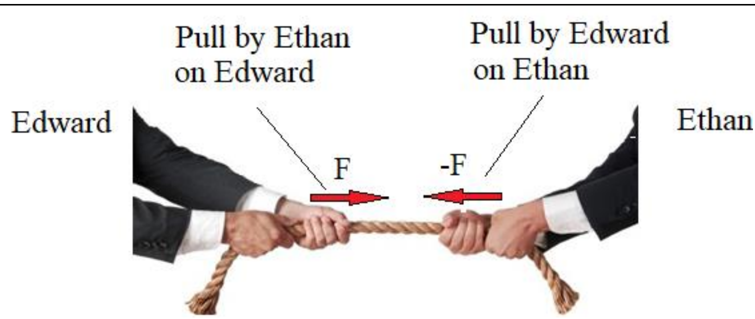
Forces are pushes and pulls. Units: "newtons" (N) A one-newton force is a small force; it's the force a hand holding a cube of butter would have to apply upward to support it.	 1.0 N ≅ ¼ lb

Newton's 3rd Law

If one object pushes or pulls on a second one, the second one pushes or pulls with equal force on the other one.



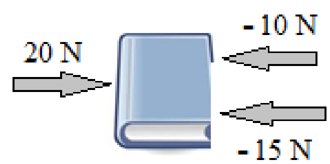
Pushes occur in pairs of equal pushes.



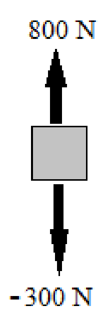
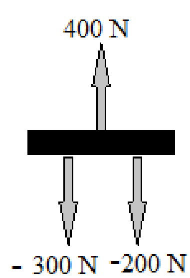
Pulls occur in pairs of equal pulls.

Adding Parallel Forces

Forces pointing left are negative. Forces pointing right are positive. The “net” force on an object is the sum of all of the forces acting on the object; it’s the “total force.”

Example A:	Example B:
 F = 12 + (-8) = 4 N Positive sign indicates the net force is directed to the right.	 F = 20 + (-25) = -5 N Negative sign indicates the net force is directed to the left.

Forces pointing downward are negative.
Forces pointing upward are positive.

Example C:	Example D:
 F = 800 + (- 300) = 500 N Net force is upward.	 F = 400 - 300 - 200 = -100 N Net force is downward.

Adding Non-Parallel Forces

<u>Example A</u>:

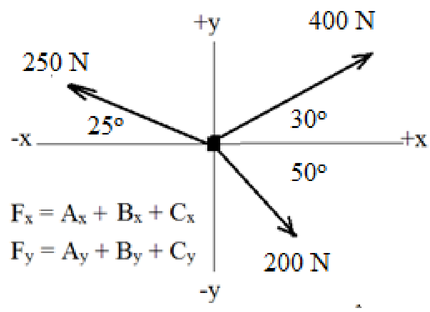
Three forces act on the object at the origin of the x-y plane.

A = 400 N, 30° above +x-axis
B = 200 N, 50° below +x-axis
C = 250 N, 25° above -x-axis

Find the magnitude of the net force.

You may need to review the vector component sign rules provided in Chapter One for displacement vectors; the rules are the same for force vectors.

Solution appears at the right.



F = A + B + C

$F_x = A_x + B_x + C_x$
$= 400 \cos 30 + 200 \cos 50 - 250 \cos 25$
$= 248.39$ N

$F_y = A_y + B_y + C_y$
$= 400 \sin 30 - 200 \sin 50 + 250 \sin 25$
$= 152.45$ N

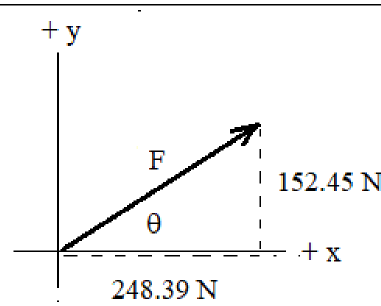
$F = (F_x^2 + F_y^2)^{1/2}$
$= (248.39^2 + 152.45^2)^{1/2}$
$= 291.44$ N

<u>Example B</u>:

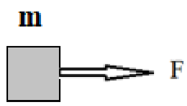
What is the direction relative to the +x axis of the net force in the example above?

$\theta = \text{Tan}^{-1}\,(152.45/248.39)$
$= 31.54°$

(Above the + x axis)



Newton's Second Law



F is the net force.

F = m**a**

Written in component form, the vector equation above becomes

$F_x = ma_x$
$F_y = ma_y$

Alternatively:

$a_x = F_x/m$
$a_y = F_y/m$

<u>Example</u>:

A 4 kg object is initially at rest. A net force F, whose components are listed below, is then applied.

$F_x = 16$ N
$F_y = 24$ N

What is the object's speed 3.0 seconds after the force is applied?

The speed of an object is the magnitude (length) of its velocity vector. Recall: Lengths of vectors are found using the square root of the sum of the squares of the x- and y-components.

$$\text{speed} = (v_x^2 + v_y^2)^{1/2}$$

<u>Obtain v_x</u>:

$a_x = F_x/\ m$
$\quad = 16/4$
$\quad = 4\ \text{m/s}^2$

$v_x = v_{ox} + a_x t$
$\quad = 0 + 4\ (3)$
$\quad = 12$ m/s

<u>Obtain v_y</u>:

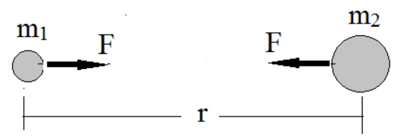
$a_y = F_y/\ m$
$\quad = 24/4$
$\quad = 6\ \text{m/s}^2$

$v_y = v_{oy} + a_y t$
$\quad = 0 + 6\ (3)$
$\quad = 18$ m/s

$$\text{speed} = (12^2 + 18^2)^{1/2}$$
$$= 21.63 \text{ m/s}$$

Universal Law of Gravitation

$$F = \frac{Gm_1m_2}{r^2}$$



Universal Gravitational Constant:
$G = 6.67\ 10^{-11}$ N-m^2/kg^2

r = distance between centers

Example:

A planet of mass M = 6.0×10^{25} kg is orbited by a moon whose mass m is 2.0×10^{20} kg. The distance between their centers is r = 4.0×10^{8} m.

What force does the planet exert on the moon, and vice-versa?

$F = 6.67 \times 10^{-11}$ N-m^2/kg^2 $(6.0 \times 10^{25}$ kg$)(2.0 \times 10^{20}$ kg$)$ / $(4.0 \times 10^{8}$ m$)^2$
$= 5.0 \times 10^{18}$ N

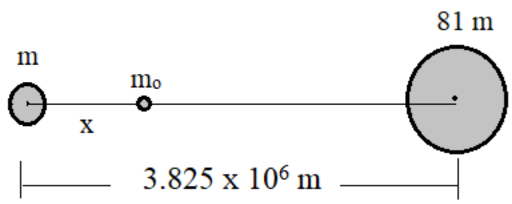
This is the force Earth exerts on the moon. By Newton's Third law, the moon exerts the same force on Earth.

Example A:	Example B:
The gravitational force exerted on each other by two objects is 2700 N. What will be the new force if the distance between the objects is tripled? Initial Force: $F = Gm_1m_2/r^2$ $= 2700$ N New Force: $F = Gm_1m_2/(3r)^2$ $= (1/9)\ Gm_1m_2/r^2$ $= (1/9)\ 2700$ $= 300$ N	Two objects are moving toward each other. At a certain instant when the separation between the objects is 14.0 m, the gravitational force each exerts on the other is 400 N. Later, the force has grown to 2800 N. What is the separation then? Initially: $Gm_1m_2/14^2 = 400$ N Later: $Gm_1m_2/r^2 = 2800$ N Divide: $r^2/14^2 = 400 / 2800$ $r = 5.29$ m

Example:

Earth's mass is about 81 times the moon's mass. At what distance from the moon (call it x), on a line connecting the moon and Earth, would the net force on an object be zero? Call the object's mass m_o.

The distance from moon to Earth is about 3.825×10^5 m.



Pull by Earth on m_o = Pull by Moon on m_o

$G (m_o)(81\ m)/(3.825 - x)^2 = G\ mm_o/x^2$

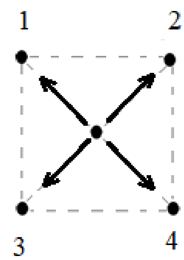
Divide both sides by $G\ (81mm_o)$, and solve for x:

$81 / (3.825 \times 10^5 - x)^2 - 1/x^2 = 0$

$x = 38{,}250$ m

Example:

The figure below shows four objects of equal mass at the vertices of a square. A fifth object is at the center of the square. What is the net gravitational force on the center object?



Solution:

Each of the vertex objects are the same distance from the center, so they each pull on the center mass with the same force.

Opposing pulls on the center object by objects at Vertices 1 and 4 cancel; likewise, opposing pulls on the center object by objects at Vertices 2 and 3 cancel.

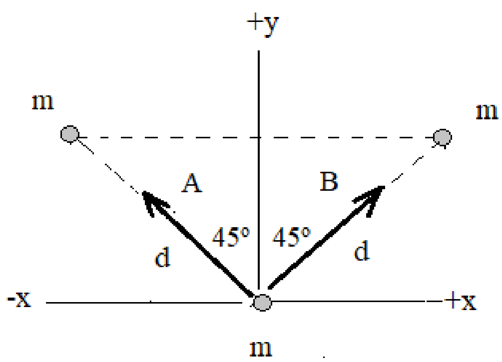
The net (total) force is zero.

Example :

The two objects of equal mass, m, are each a distance d from a third, identical, mass.

What is the net force on the center object?

Express your answer as an exact multiple of Gm^2/d^2.



Note for future use:

$\cos 45 = \sin 45$
$= \sqrt{2}/2$

Solution:

The pulls P (labeled A, and B) each exert the same force on the third object.

$A = Gm^2/d^2$
$B = Gm^2/d^2$

$F_x = A_x + B_x$
$= A \cos 45 - B \cos 45$
$= (Gm^2/d^2) \cos 45 - (Gm^2/d^2) \cos 45$
$= 0$

$F_y = A_y + B_y$
$= (Gm^2/d^2) \sin 45 + (Gm^2/d^2) \sin 45$
$= 2\,(Gm^2/d^2) \sin 45$
$= 2 \sin 45\,(Gm^2/d^2)$

The exact multiple we're looking for is

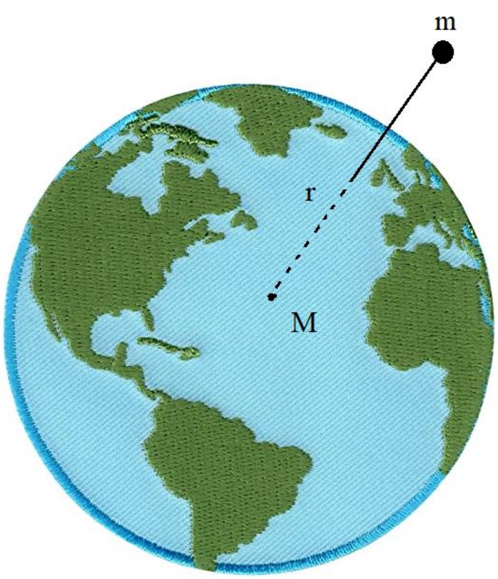
$2 \sin 45 = 2\sqrt{2}/2$
$= \sqrt{2}$

Weight

The weight of an object is the gravitational force Earth exerts on it.

The figure below shows Earth of mass M and an object of mass m which is a distance r from Earth's center. The force Earth exerts on the object is

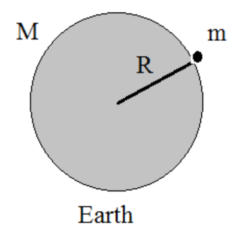
$$F = GMm/r^2$$



The weight of an object depends on the distance between its center and the center of Earth.

Example:

The figure below shows an object of mass m resting on Earth's surface. The mass of Earth and its radius are given below.



$M = 5.98 \times 10^{24}$ kg
$R = 6.38 \times 10^{6}$ m

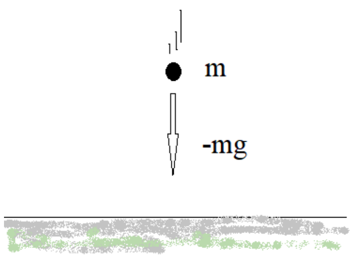
The object is on Earth's surface, so r = R.

The force Earth exerts on the object:

$$\begin{aligned} F &= GMm/R^2 \\ &= m\,(GM/R^2) \\ &= m\,(6.67\times10^{-11})\,(5.98 \times 10^{24})/(6.38 \times 10^{6})^2 \\ &= m\,(9.8) \\ &= mg \end{aligned}$$

The weight force points to the center of Earth.

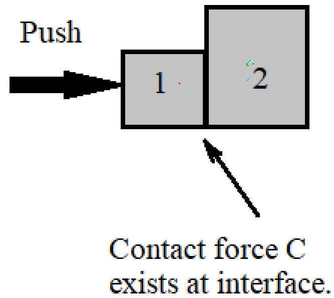
We commonly use the symbol "m" to represent the weight of an object.

Example A:	Example B:
An object of mass m is falling near the surface of Earth. What is the object's acceleration? Recall Newton's 2nd Law: $a = F/m$ $= -mg/m$ $= -g$  	An object of mass m = 10 kg is falling near Earth. Air resistance supplies a constant upward 25-N resisting force. What is the object's acceleration? $a = F/m$ $= (25 – 98)/10$ $= -7.3\ m/s^2$ 

Contact Forces

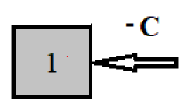
When one object is pressed against another object, each object exerts a “contact” force on the other.

By Newton’s 3rd Law, contact forces come in pairs: Whatever is the force the first object exerts on a second one, the second one exerts exactly the same force on the first one.

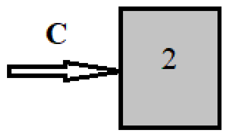


The blocks in contact exert equal but opposite forces on each other, as shown below.

Block 2 exerts force on Block 1.

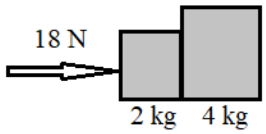


Block 1 exerts the *same* force on Block 2.

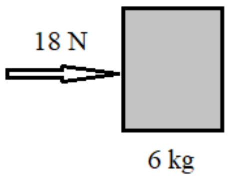


Example:

Find the value of the contact force between the two blocks below.



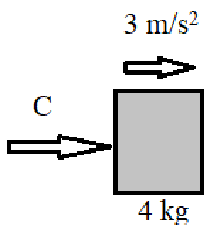
Same as:



$a = F/m$
$= 18/6$
$= 3\ m/s^2$

Each block has an acceleration of $3\ m/s^2$.

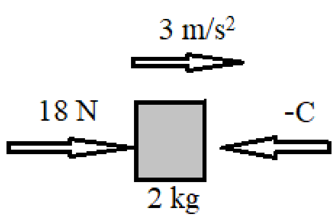
Apply the 2^{nd} Law to the 4 kg block:



$F = ma$
$C = 4(3)$
$= 12\ N$

Another way to calculate C:

Apply the 2^{nd} Law to the 2-kg block:



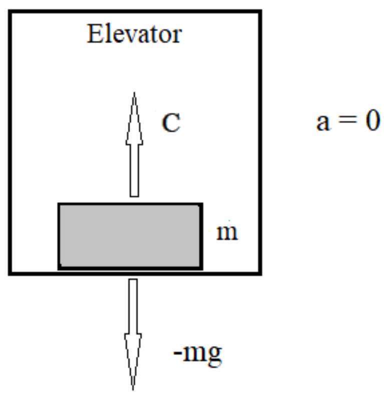
$F = ma$
$18 - C = 2\ (3)$
$C = 12\ N$

Apparent Weight

The "apparent" weight of an object on Earth's surface is not necessarily its actual weight (mg).

The apparent weight of an object is defined to be the *contact force* exerted on it by whatever horizontal surface it's resting on; it's what a bathroom scale would read, for example. It's also what you "feel" is your weight.

A 60-kg person (represented by the block in the figure at the right) is in an elevator at rest.



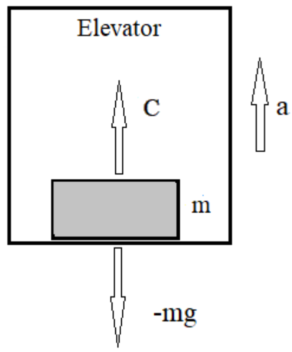
What is the person's apparent weight?

$$F = ma$$
$$C - mg = ma$$
$$C - mg = 0$$
$$C = mg$$
$$= 588\ N$$

This person's apparent weight is her actual weight.

Example:

A 60-kg person (represented by the block in the figure at the right) is in an elevator accelerating upward at $a = 4.0$ m/s^2.



What is the person's apparent weight?

$$F = ma$$
$$C - mg = ma$$
$$C - 60(9.8) = 60(4.0)$$
$$C = 828 \text{ N}$$

Compare this to the person's actual weight, which is 588 N. Accelerating upward, this person feels 240 N heavier than he did when he entered the elevator, and his knees sag a bit. This person feels as if he had a 240-N weight placed on his shoulders.

Example:

At the right, a 60-kg person (represented by the block) is in an elevator that is accelerating downward at $a = -4.0\ m/s^2$. What is his apparent weight?

$$F = ma$$
$$C - mg = ma$$
$$C - 60(9.8) = 60(-4)$$
$$C = 348\ N$$

This person feels much lighter on his feet. His actual weight is 588 N, but he feels as if he just lost 240 N (about 60 lbs).