Physics 17 Part C1

Newton's Laws of Motion

A $20 bill has a mass of about one gram. One "classic" M& M candy also has a mass of about one gram (g). A penny has a mass of about three grams.

The Standard International (SI) unit for mass is the kilogram (kg):

1 kilogram = 1000 grams

Average adult body mass globally is 62 kg (136.4 lbs).

Interesting Fact: One kilogram of *any* substance has a weight of about 2.2 pounds (lbs)….one kilogram of gold, one kilogram of water, one kilogram of air, one thousand $20 bills…..all weigh about 2.2 lbs.

1 gram each

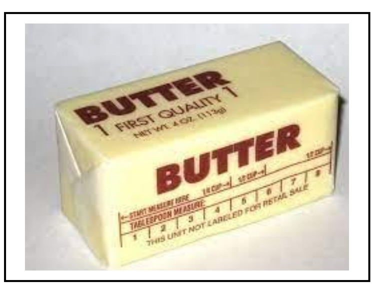
3 grams

1 gram

Force

Forces are pushes and pulls. The standard unit for force is the "newton" (N).

A newton of force is about one-quarter of a pound, the weight of a cube of butter.



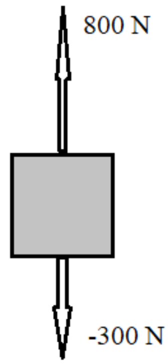
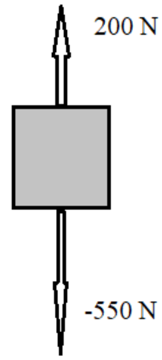
1 N ≅ ¼ lb

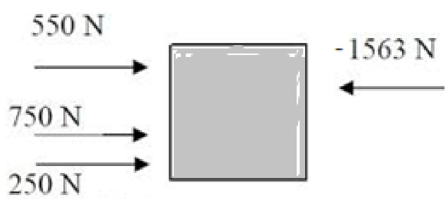
Lifting a cube of butter requires about one-newton of force.

The most common symbol for force is "F."

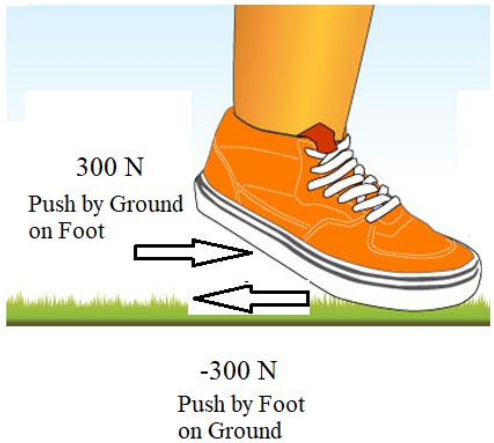
Net Forces

The “net” force, also called “total” force, is just the sum of the forces. The sum of the two forces acting on the book on the right is F = 12 + (-8) = 4 N. The net force is directed to the <u>right</u>, because F is positive. The book will move to the right.	 The positive direction is to the right; the negative direction is to the left.
The net force on the book on the right is F = 30 + (- 45) = - 15 N The net force is directed to the <u>left</u>, because F is negative. The book will move to the left.	

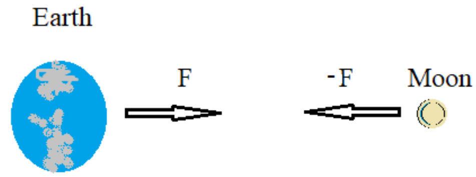
Forces with negative signs are directed downward, in the negative direction. Forces that are positive point upward, in the positive direction. In Figure 1, the net force is F = 800 + (-300) = 500 N (upward) In Figure 2, the net force is F = 200 + (-550) = -350 N (downward)	 F = 500 N Figure 1	 F = -350 N Figure 2

The net force acting on the object at the right is F = 550 + 750 + 250 + (-1563) = -13 N This object experiences a net force directed to the left.	 F = -13 N

Newton's Third Law



Pushes occur in pairs of equal but oppositely directed pushes. The foot pushes on the ground, and the ground pushes with the same force on the foot.



Pulls also occur in pairs of equal but opposite forces. Earth pulls on the Moon, and the Moon pulls with an equal force Earth.

This rule is called "Newton's Third Law of Motion."

Newton's Second Law of Motion

When a "net" (total) force acts on an object, the object accelerates in the direction of the force:

$$a = F/m$$

An alternative form--the more common form-- of Newton's 2nd Law is shown below:

$$F = ma$$

Example A:

An object of mass m = 2 kg is initially moving at 3 m/s. A net force F = 10 N directed to the right is then applied to the object.

What is the object's acceleration?

$$\begin{aligned} a &= F/m \\ &= 10 / 2 \\ &= 5\ m/s^2 \end{aligned}$$

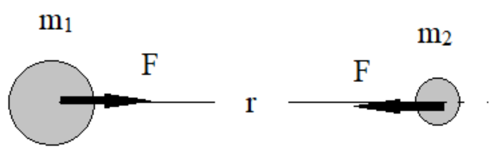
Example B:

m = 4 kg	a = 3 m/s^2	F = ?

$$\begin{aligned} F &= ma \\ &= (4)\ (3) \\ &= 12\ N \end{aligned}$$

The Universal Law of Gravitation

All objects attract (pull on) every other object in the universe. The force of attraction is said to be "mutual" because each object exerts the *same* force on the other one. The equation one can use to calculate the mutual force of attraction is shown below:



$$\mathbf{F = G\, m_1 m_2 / r^2}$$

G = "Universal Gravitational Constant"
$= 6.67 \times 10^{-11}$ N-m^2/kg^2
r = Distance between Centers of Objects

<u>Example</u>:

An asteroid of mass $m_1 = 2.0 \times 10^9$ kg is 100 meters away from a second asteroid whose mass is $m_2 = 3.0 \times 10^8$ kg. What is the mutual force of attraction the asteroids experience?

$F = (6.67 \times 10^{-11}\ \text{N-m}^2/\text{kg}^2)\ (2.0 \times 10^9\ \text{kg})(3.0 \times 10^8\ \text{kg})/(100\ \text{m})^2$
$= 4002$ N

Example:

The mutual force of attraction two asteroids of equal mass m exert on each other is 2000 N. Suppose the mass of one of the asteroids increases by ten percent, and the separation between their centers is halved.

What will be the new force of attraction?

Before the changes:

$F = G\, m\, m/r^2$

$= 2000$ N

After the changes:

$F = G\,(1.10\, m)\, m\, /\, (0.5\, r)^2$

$= (1.10) / (0.5)^2\, (G\, mm/\, r^2)$

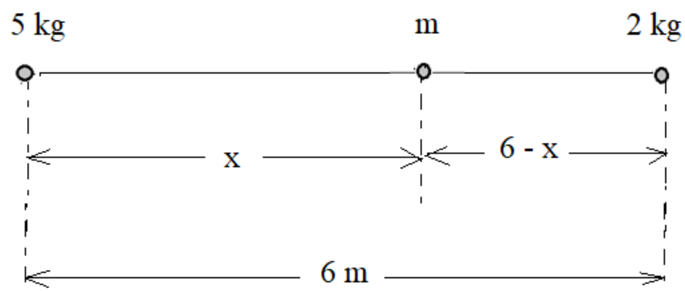
$= 4.40\, (G\, mm\, /r^2)$

$= 4.40\, (2000)$

$= 8800$ N

Example:

The figure below shows a 5-kg object located 6.0 meters away from a 2-kg object. How far (call it x) to the right of the 5-kg object above may an object of mass m be placed for the net gravitational force on it to be zero?



Solution:

The mass m will be at a point x that satisfies the following condition:

$$0 < x < 6 \text{ m}$$

The sum of the two pulls on the mass m is zero. The pull by 5 kg is directed to the left, so it's negative, while the pull by 2 kg is directed to the right, so it's positive:

$$- G(5)\, m/x^2 + G(2)\, m/(6 - x)^2 = 0$$

Divide both sides by Gm:

$$5/x^2 = 2/(6 - x)^2$$

This is a quadratic equation, so it has two solutions:

$$x = 3.68 \text{ m and } x = 16.32 \text{ m}$$

The larger of the two numbers is outside the acceptable range, so we accept x = 3.68 m as the answer.

Weight

The weight of an object on or "near" Earth is defined to be the gravitational pull Earth exerts on the object. This pulling force is always directed from the object to the center of Earth.

Mass of Earth: $M = 5.98 \times 10^{24}$ kg
Radius of Earth: $R = 6.38 \times 10^{6}$ m
(about 4000 miles)

If an object is, say, no higher than about 10 miles above Earth's surface, then $r \cong R$ is good approximation.

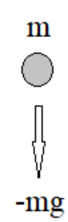
$$
\begin{aligned}
F &= GMm/R^2 \\
&= m\,(GM/R^2) \\
&= m\,(6.67 \times 10^{-11})(5.98 \times 10^{24})/(6.38 \times 10^{6})^2 \\
&= m\,(9.8) \\
&= mg
\end{aligned}
$$

The symbol used for the weight of any object on or near the surface of Earth is "w."

$$\mathbf{w = mg}$$

Example:

What is the acceleration of an object falling near Earth's surface?



Newton's Second Law:
$a = F/m$
$= -mg/m$
$= -g$
$= -9.8$ m/s^2
The negative sign indicates that the object is accelerating downward.

Example:

Suppose an object's weight on or near Earth's surface ($r \cong R$) is 900 N.

$F = GMm/r^2$ (Equation 1)
$= GMm/R^2$
$= 900$ N

(a) What will be its weight when the distance between the center of Earth and the center of the object is tripled to r = 3 R?

Tripling r:

$F = GMm/(3R)^2$
$= (GMm/R^2) / 9$
$= (900 \text{ N}) / 9$
$= 100$ N

Quicker: Tripling r will cause the denominator of Equation 1 to be $3^2 = 9$ times greater, which means the force F in Equation 1 will become one-ninth of what it was before the tripling of r. Therefore, the new weight force will be

$F = (1/9)$ 900 N
$= 100$ N

(b) What altitude is this when r = 3 R?

The altitude is the distance above the ground, which is 3 R – R:

Answer: 2 R