Newton's Second Law

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CONCEPT 1

Newton's Second Law

- Define Newton's Second Law and net force
- Calculate acceleration from force and mass
- Calculate force from acceleration and mass
- Calculate mass from force and acceleration

Newton's Second Law:

Kick a small stone and it moves fairly fast. Kick a larger stone with the same force and it doesn't move so fast. We hypothesize that force is capable of producing acceleration and the size of acceleration is dependent upon the mass of the object to which the force is applied. If we use, without stating a precision definition, the term "mass," we see a relationship between the net force, acceleration and mass.

Newton's Second Law: The acceleration, a, of an object is directly proportional to the net force, ΣF, upon it and inversely proportional to its mass, m.

As long as one force is involved, this is pretty simple. The more massive something is, the harder you have to push it – and the harder you push it, the more you can accelerate it. These are all *linearly proportional*, which means that they are found by simple multiplication. Suppose on a muddy day, an opposing player with the ball loses his footing and starts slipping toward you, and you bring him to a stop. Because he slipped, he's not pushing back, so your push is the only force on him. Suppose later that game, a similar case happens. In this case, linearly proportional means compared to your first try:

- If you use twice as much force, you can accelerate the next player twice as quickly – bringing him to a stop in half the time.
- If you use twice as much force, you can accelerate a player twice as massive – bringing them to a stop in the same time. If the new player is twice as massive, it would take twice as much force to accelerate them the same amount. Alternately, if the new player is twice as massive and you apply the same force, he will only accelerate half as much – so he would come to a stop more slowly, taking twice as long.
- If the new player comes to a stop twice as quickly (twice the acceleration), then he may have had twice the force applied to him. Alternately, if the new player comes to a stop twice as quickly (twice the acceleration), then he may have the same force applied to him, but he is only half as massive.

Units of Force

When you calculate force, if you use mass in kilograms

(kg)

and acceleration in meters per second squared

$(\mathrm{m/s^2})$

, then the resulting force comes out in a unit called the "Newton" after Isaac Newton. If you're using other units, you'll need to convert. In American Imperial units, the pound is used as both as a measure of mass and force. The conversions are:

- 1 pound (lbs) = 0.45 kilograms (kg)
- 1 pound (lbs) = 4.4 Newtons (N)

Side Note: The unit "Newton" is written with a capital N. Units that are named after people are capitalized just like that person's name, while other units are not – such as meter or kilogram.

Calculating Acceleration From Force

Mass is the "stuff" (matter) that an object possesses whereas the pull by gravity on mass is the mass's weight. The more mass an object has, the more inertia it has, and the more weight it has at a particular location.

However, we do not need gravity to define mass. Imagine, for instance, a rectangular block of wood of mass m resting upon a horizontal frictionless surface.

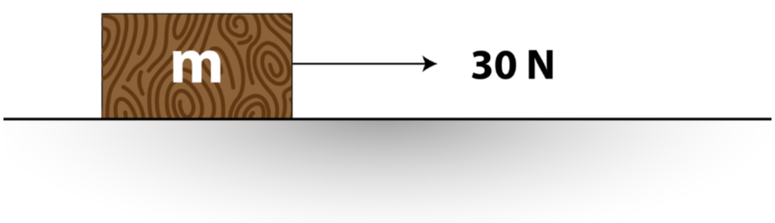

FIGURE 1.1
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A block accelerates along a frictionless table due to a horizontal force of 30.0 N acting upon it. (The force of gravity and the normal force also act upon the block, but these forces do not enter into our discussion. We will have more to say about these when we discuss Free Body Diagrams.)

Measuring the position of the block as a function of time, we are able to determine the acceleration of the block is 2.00 m/s^2. Since $F = ma$, we have 30 $N = m(2.0\ m/s^2)$ and $m = 15\ kg$. Notice we did not use gravity to determine the mass of the block.

Had we weighed the block we would have found its weight to be 147 N. Using $W = mg$, we find the block's mass as 15 kg.

http://demonstrations.wolfram.com/NewtonsSecondLaw

Things to ponder:

1. Newton's First Law defines what we mean by an inertial frame. Physics is easier to interpret from the point of

view of an inertial frame.

2. One object may be subject to many forces. A question stating that an object has forces acting upon it yet the object moves with a constant velocity is indirectly stating that the net force on the object is zero. For example: A person places a 100 N force upon a box while moving it with a constant velocity of 2 m/s. This statement is indirectly stating that another 100 N force (or forces adding up to 100 N) is directed opposite the 100-N force that the person is applying.

Mass vs. Weight

Mass is a scalar quantity having units of kilograms and weight is a vector quantity measured in newtons. Your mass does not change regardless of where you are in the universe. Your weight on the other hand is dependent upon gravitational acceleration. Hence your weight changes depending upon which planet you're on.

We use the word "gravity" to represent the force that keeps our feet on the ground. When we jump, we don't just keep moving upward. We reach a highest point, depending on how much effort we put into the jump, and then fall back to the earth. Galileo determined that the acceleration, g, due to gravity for all falling bodies close to the earth's surface has a numerical value of about 10 m/s^2. It is important not to confuse the acceleration due to gravity, g, and the force of gravity W or mg.

Weight, W, is defined as the product of mass, m, and acceleration due to gravity, g: $W = mg$. The weight of a 1.0 kg mass is: $W = (10 \text{ m/s}^2)(1.0\text{kg}) = 10 \text{ kg} \times \text{m/s}^2 = 10\text{N}$. The weight is 10 Newtons.

Check your understanding

1. The mass of a 1.00-N weight is:

a. 1.0 kg
b. 10. kg
c. 0.10 kg

Answer: (c) $W = mg$ so $m = \frac{W}{g}$. Putting in the weight of 1 Newton and g, we get $\frac{1\ N}{10\ m/s^2} = 0.10\text{kg}$.

2. What is the force of gravity acting on a 15.0-kg mass?

Answer: $W = mg = (15.0)(9.81) = 147\ N$

3. Find the acceleration due to gravity in the following cases.

a. A 70.0 kg astronaut weighs 261.1 N on the Mars. Find the acceleration of gravity on the surface of the Mars.
b. A 70.0 kg astronaut weighs 113.4 N on the Moon. Find the acceleration of gravity on the surface of the Moon.

Answers:

a. $W = mg$; $g = \frac{261.1\ N}{70.0\ kg} = 3.73\ m/s^2$.

b. $W = mg$; $g = \frac{113.4\ N}{70.0\ kg} = 1.62\ m/s^2$.

http://www.flashscience.com/motion/weight_on_planets.htm

http://demonstrations.wolfram.com/FreeFallOnTheSolarSystemPlanetsAndTheMoon/

Mass is the "stuff" (matter) that an object possesses whereas the pull by gravity on mass is the mass's weight. The more mass an object has, the more inertia it has, and the more weight it has at a particular location.

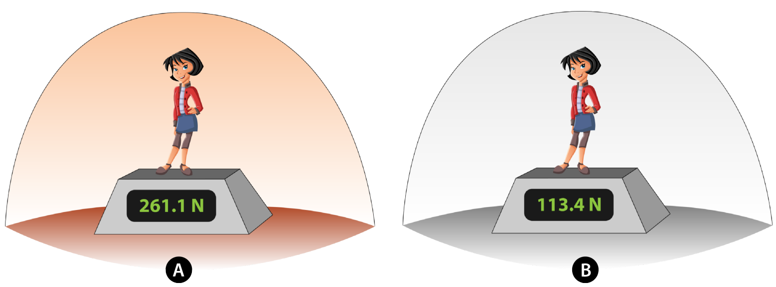

FIGURE 1.2

(A) Person weighing on Mars. (B) Person weighing on Moon. Author: Image copyright Denis Cristo, 2012; modified by CK-12 Foundation - Christopher Auyeung License: Used under license from Shutterstock.com Source: http://www.shutterstock.com