Unit 7

Force and mass

"Nature and Nature's laws lay hid in night; God said, Let Newton be! and all was light."
Alexander Pope

"If I have been able to see further, it was only because I stood on the shoulders of giants."
Sir Isaac Newton

1. Forces and its effects

The **mass** of an object is the amount of matter in it.

It is impossible to define a **force**. Instead of defining what forces are, (all attempts in history failed because of definitions in circles), scientists usually centre on what forces do.
A thumb tack is attracted by a magnet, an apple falls from a tree due to gravity, and a spring streches if you place a weight on one of its ends.

When bodies interact they can cause changes (deformations) to the interacting bodies, or changes in their state of motion (accelaration). In order to measure how bodies interact, physisists use the magnitude kown as force.

Forces are physical magnitudes which deform bodies or modify their state of motion.

There are two general kinds of forces: **contact forces** which act when objects touch (example: the force exerted by a hammer hitting a nail) and **non-contact forces** which act at a distance (the force exerted by a magnet on steel pins).

The stronger the intensity or magnitude of the force, the greater its effect. Forces are vectorial magnitudes and the SI (International System) unit of force is the **newton (N)**.

$$1\ N = 1\ kg \cdot m/s^2$$

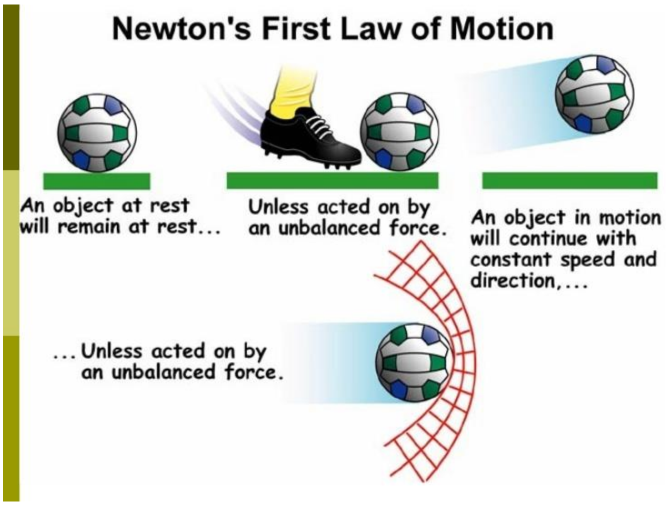
2. The 4 Fundamental Forces of Nature

- Gravitational Force: It acts between any two pieces of matter as mass is its source. It is why objects fall or why planets turn around the Sun.
- Electromagnetic Force, which cause electric and magnetic effects such as the interactions between magnets.
- Weak Nuclear Force: It is responsible for radioactive decay.
- Strong Nuclear Force: It is responsible for holding the nuclei of atoms together (holds neutrons and protons together)

3. Newton's Laws of Motion

The English physicist and mathematician **Isaac Newton (1642-1727)** is arguably the most influential scientist of all times. Newton refined Galileo's experimental method, creating the compositional method of experimentation still practiced today. Applying his scientific method, Newton formulated a unified system of laws, that could be applied to an enormous range of physical phenomena, and used to make exact predications. Newton published his works in two books, namely "Opticks" and "Principia."

- Newton´s first law (or the Law of Inertia): An object will remain at rest or in motion with the same speed and in the same direction (uniformly rectilinear motion) unless an external, unbalanced force acts upon it.

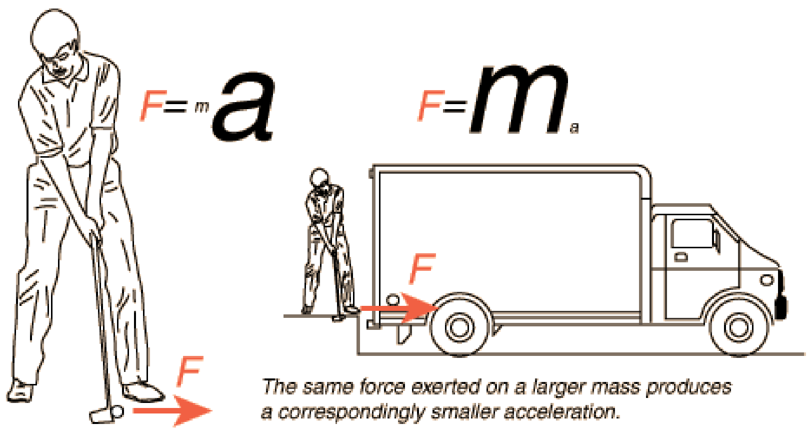


("Information security", 2018)

- Newton´s second law (or the Fundamental Law of Dynamics): Acceleration is produced when a force acts on a mass. The greater the mass (of the object being accelerated) the greater the amount of force needed (to accelerate the object).

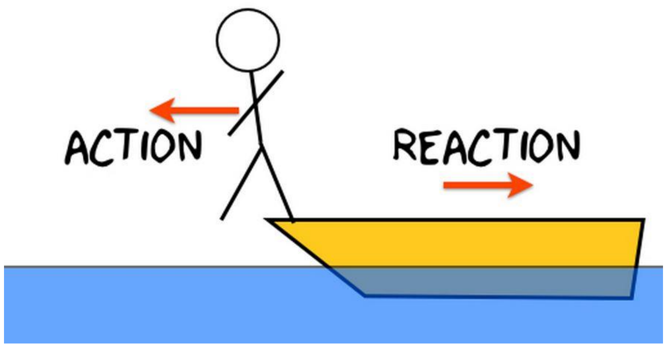
(The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object)

$$\mathbf{F = m \cdot a}$$



(“Newton’s Laws”, 2018)

- Newton's third law (or the Law of Reciprocal Actions): For every action there is an equal and opposite reaction.



(Thipparthi, 2018)

4. The Force of Friction

Friction is a resistive force that opposes the relative motion of two surfaces in contact with one another. Friction is due to the interaction between the molecules of the two surfaces that are touching. Friction is what allows your shoes to grip the sidewalk, or a car’s tires to grab the road.

(**Static friction** is the friction between two surfaces that are at rest relative to one another. It is a force between two surfaces that prevents those surfaces form sliding or slipping across each other. **Kinetic friction** is the friction between two surfaces that are moving relative to one another. Kinetic friction always opposes the sliding motion and tries to reduce the speed at which the surfaces slide across each other).

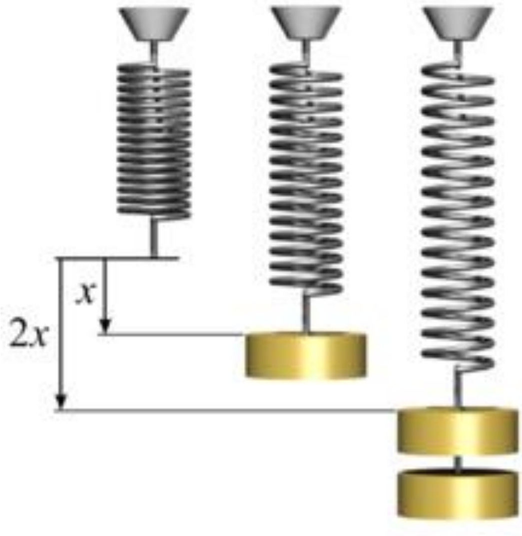
5. Hooke's Law

The deformation forces produced in a body are of two kinds. In **elastic bodies**, the body regains the initial form once the force stops acting upon it (example: a rubber band). In **plastic bodies**, the initial form of the body is not regained if the force is removed; the deformation is permanent (example: play dough).

Hooke's law stablishes that **the deformation of a body is proportional to the magnitude of the force acting upon it, (provided that the body's elastic limit is not exceeded**. The elastic limit is the point at which a certain amount of force will deform the material so it becomes non-elastic).

$$\mathbf{F = K \cdot x}$$

where x represents how much the body has stretched or shrunk, and K is the elastic constant of the body. K is measured in N/m.



("Hooke's law", 2018)

This means that when you add mass to a spring in equal quantities, it will elongate by equal amounts. The K, the spring constant, will be different for different springs

Example: If a spring is stretched by 2 cm by a weight of 1 N, it will be stretched by 4 cm by a weight of 2 N, and so on. However, once the load exceeds the elastic limit for the spring, Hooke's law will no longer be obeyed and each successive increase in weight will result in a greater extension until finally the spring breaks.

6. The Force of Gravity

Through a multitude of observations, Newton came to the conclusion that all objects in the Universe exerts gravitational forces on each other.

Newton went on to formulate a law called **the Law of Universal Gravitation**:

Two bodies exert a force of attraction on one another that is directly proportional to the masses of the bodies and inversely proportional to the square of the distance which separates them

$$F = G \cdot \frac{m_1 \cdot m_2}{d^2}$$

F = the gravitational force
G = Universal gravitational constant (discovered by Henry Cavendish in 1798):

$G = 6.67 \cdot 10^{-11}\ N \cdot m^2/kg^2$

m_1 and m_2 = the masses of the two objects
d = the distance between the two objects

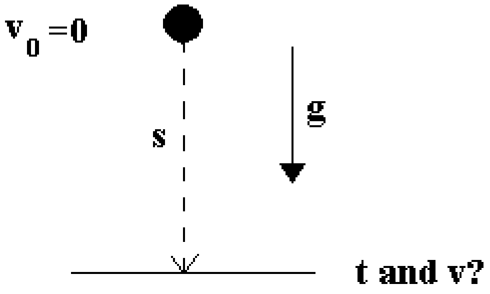
If we have an object on the surface of the Earth, the distance between the object and the centre of the Earth is equal to the radius of the planet Earth (r = 6370 km)
In this case, the equation will be the following:

$F = G \cdot \frac{M_1 \cdot m_2}{r^2}$, where M_1 is the mass of the Earth ($5,98 \cdot 10^{24}$ kg), m_2 is the mass of the object, and r^2 is the square of the radius of the planet Earth.

7. Free Fall movement

The free fall movement is a uniformly accelerated rectilinear movement, with a constant acceleration which is equal to the acceleration caused by gravity, **$g = 9,8\ m/s^2$**.

Example: If we let a mobile fall ($v_0 = 0$) from a determined height (s), we can calculate the time it takes to fall and the velocity with which it reaches the floor:



$$e = \frac{g \cdot t^2}{2} \Rightarrow t = \sqrt{\frac{2 \cdot e}{g}}$$

$$\mathbf{v = g \cdot t}$$

8. Force Weight

The force weight is the gravitational force with which Earth attracts bodies with mass.

$$F = m \bullet a \quad \rightarrow \quad F_w = m \bullet g$$

Applying Newton's second law of dynamics, we obtain the formula for the force Weight.

The value of the weight of bodies, and consequently also the acceleration caused by gravity, diminishes with altitude.

9. Magnetism

You have probably, at some time in your life, played with magnets, seeing how they interact with other magnets. And you probably realized that sometimes they attract one another and sometimes they repel one another

Magnetism is the property that some objects have to attract other objects such as iron, cobalt, nickel, etc. These objects are called **magnets**, and the forces they generate are called **magnetic forces**. There are natural and artificial magnets. Artificial magnets are made by putting them in contact with another magnet, or with the use of an electric current (electromagnets)

("Isolated horseshoe magnet attracting metal nails and screws", 2018)

Every magnet has **two magnetic poles**: a north pole (N) and a south pole (S). In magnets, like poles repel while opposite poles attract. A magnet has a magnetic field in the space around it. In this space, there are forces on any magnetic material there. If you place a bar magnet under a piece of paper, then sprinkle iron filings on the paper, you will see the iron filings line up in a distinct pattern around the magnet. The iron filings reveal the **magnetic field**.

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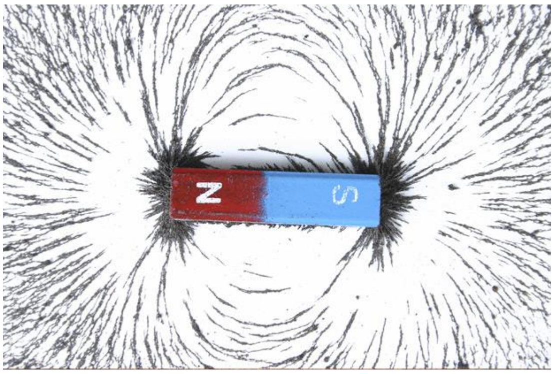

("Electricity and Magnetism", 2018)

References

Bethel, D. (2006). Physical science (1st ed.). Austin, TX: Steck-Vaughn Co./Harcourt Achieve.

Electricity and Magnetism. (2018). *Mrs. Sanford's All-Stars*. Retrieved 26 April 2018, from http://pamelasanford.typepad.com/5thgrade/electricity-and-magnetism.html

Hooke's law. (2018). En.wikipedia.org. Retrieved 25 April 2018, from https://en.wikipedia.org/wiki/Hooke%27s_law

Information security. (2018). Pinterest. Retrieved 25 April 2018, from https://www.pinterest.es/pin/573646071266387796/?lp=true

Isolated horseshoe magnet attracting metal nails and screws. (2018). *123RF Stock Photos*. Retrieved 26 April 2018, from https://www.123rf.com/photo_14587975_isolated-horseshoe-magnet-attracting-metal-nails-and-screws.html

Levers have a lot of Class | City Technology. (2017). Citytechnology.org. Retrieved 25 May 2017, from http://www.citytechnology.org/stuff-that-works/levers-have-a-lot-of-class

Mocomi-Fun Learning Website for Kids–Discover, Explore, Play. (2017). Mocomi Kids. Retrieved 25 May 2017, from http://mocomi.com/

Newton's Laws. (2018). Hyperphysics.phy-astr.gsu.edu. Retrieved 25 April 2018, from http://hyperphysics.phy-astr.gsu.edu/hbase/Newt.html

Pictures to Pin on Pinterest - PinsDaddy. (2017). Pinsdaddy.com. Retrieved 25 May 2017, from http://www.pinsdaddy.com

Pople, S. (2007). Complete physics for IGCSE (1st ed.). Oxford: Oxford University Press.

Pople, S. (2001). Physics. Oxford: Oxford University Press.

Simple Machines By Joanne Griffin. - ppt download. (2017). Slideplayer.com. Retrieved 25 May 2017, from http://slideplayer.com/slide/2380340/

The Pulley (by George Herbert). (2017). R::OOM to think. Retrieved 25 May 2017, from https://radicaloneofmany.wordpress.com/2009/02/25/the-pulley-by-george-herbert/

Thipparthi, V. (2018). Research Shows Newton's Third Law Violation With Surprising Results. Fossbytes. Retrieved 25 April 2018, from https://fossbytes.com/non-equilibrium-mixtures-violating-newtons-third-law-show-surprising-results/

What is friction?. (2018). Khan Academy. Retrieved 25 April 2018, from https://www.khanacademy.org/science/physics/forces-newtons-laws/inclined-planes-friction/a/what-is-friction

Wedge Examples. (2017). Softschools.com. Retrieved 25 May 2017, from http://www.softschools.com/examples/simple_machines/wedge_examples/507/

Exercises

Circle the correct answer:

1. Newton's first law is also called:

   a) The law of force b) the law of motion c) the law of inertia

2. Which of the following expresses Newton's second law?

   a) F = ma b) Fg = G (m^1 m^2) / r^2 c) p = mv

3. Which of the following expresses Newton's third law?

   a) Acceleration is always accompanied by a force.
   b) Every action force is accompanied by an equal and opposite reaction force.
   c) Objects tend to remain at rest or in motion at a constant speed.

4. Which quantity measures the amount of matter in an object?

   a) Mass b) weight c) force

5. Which is the SI unit for weight?

   a) kg b) N c) g d) (kg)(m) / s

6. Newton's law of universal gravitation can be applied

   a) only to very massive objects
   b) only to objects in outer space
   c) only to objects near Earth's surface
   d) to any two objects with mass

7. What kind of force opposes the relative motion of two contacting surfaces?

   a) normal force b) gravitational force c) friction

8. Explain the difference between static friction and kinetic friction

Newtown's Laws

1 A 1520 kg car accelerates at a rate of 1.5 m/s^2. What is the force on the car? Answer: 2280 N (2.28 x 10^3 N)

2 A 5.22 x 10^7 kg cruise ship is moving at its top speed as it comes into port. The ship then undergoes acceleration equal to -0.357 m/s^2 until it comes to rest at its anchorage. What is the net force acting on the ship as it slows down? Answer: - 1.86 x 10^7 N

3 A catcher in a professional baseball game exerts a force of -65 N to top the ball. If the baseball has a mass of 0.145 kg, what is the ball's acceleration as it is being caught? Answer: - 448 m/s^2

4 A stone is dropped from rest. What is its speed a) after 1 s, b) after 2 s, c) after 5 s. Answer: a) 10 m/s b) 20m/s c) 50m/s

5 A stone is thrown downwards at 20 m/s. What is the speed a) after 1 s, b) after 2s, c)after 5 s. Answer: a) 30 m/s b) 40m/s c) 70m/s

6 We let an object fall from a height of 45 m. Determine the time it takes to reach the floor and the velocity it has at the moment of hitting the floor; g = 10 m/s^2. Answer: a) t = 3 s b) v = 30m/s

7 We throw an object vertically upwards with an initial velocity of 108 km/h. How long (time in seconds) will it take to reach its maximum height? What would be the value of this maximum height? g = 10 m/s^2. Answer: a) 3 s b) 45 m

8 We throw a stone from a bridge with an initial velocity of 18 km/h, and it takes 2 s to reach the surface of the water. Calculate: a) the velocity of the stone as it hits the water, b) the height of the bridge, and c) the velocity of the stone after half a second of being thrown; g = 10 m/s^2. Answer: a) v = 25 m/ s b) 30 m c) 10 m/s

9 Determine the initial velocity of a ball which falls from a balcony, knowing that it takes 1.5 s to reach the ground with a final velocity of 108 km/h. What is the height of the balcony? What is the velocity of the ball after 1 second, from the time it falls from the balcony? g = 10 m/s^2. . Answer: a) u = 15 m/ s b) 33,75 m c) 25 m/s

10 The same force is applied to two different objects. The resulting acceleration of the first object is 1.8 m/s^2 and of the second object is 9.8 m/s^2. Explain which of the two objects have the greatest mass.

Force Weight (mass and weight)

11 Work out the weights of each of the masses below, assuming that g= 10m/s^2. a) 2 kg, b) 5.5 kg, c) 0.4 kg, d) 28 kg.
Answer: a)Fw = 20 N b) Fw = 55 N c) Fw = 4 N d) Fw = 280 N

12 An object weighs 125 N in a place where the acceleration caused by gravity is 10 m/s^2. What is the mass of the object? What is the object's weight in a place where the acceleration caused by gravity is 9.65 m/s^2?
Answer: a) m = 12.5 kg b) Fw = 120.6 N

13 What would be the acceleration of a 28 tonne lorry if it takes 100 seconds to speed up from 36 km/h to 54 km/h. And what would be the force exerted by the lorry?
Answer: a) a = 0.05 m/s^2 b) F = 1400 N

Hooke's Law:

1. A spring has a constant of 2 N/m and a length of 40 cm without a load on it.
   a) Calculate the extension produced to the spring by a load of 0.4N.
   b) Calculate the load we need to stretch it 8000 mm?
   Answer: a) 60 cm, b) F = 0.8 N
2. We have a spring holding a 400 g object. Such load is stretching the spring 40 cm. Determine the length of the spring without the load. The constant of the spring is 10.5 N/m g = 10 m/s^2.
   Answer: a) 0.02 m
   As we pull a spring of 30 cm with a force of 200 N it stretches until it reaches a length of 35 cm. What is the constant, k, of the spring?
   Answer: k = 4000 N/m
3. Calculate the load (force) applied to a spring (k=200 N/m) with a length of 15 cm, in order to stretch to 25 cm.
   Answer: F= 200 N
4. We have a bag hung from a spring with 18 identical marbles. The mass of each marble is 3 grams, and the spring's constant is 1.25 N/m.
   a) determine the deformation of the spring and
   b) determine the final length of the spring if the initial length was 60 cm.
   g = 10 m/s^2.
   Answer: a) 0.43 m b) 1.03 m

The Law of Universal Gravitation:

1. What is the force of attraction between two objects (bodies) if the first one has a mass of 10 kg and the second body has a mass of 5 kg, if they are separated by 500 cm. $G = 6{,}7 \times 10^{-11}$ N m^2/kg^2.
   Answer: 1.334×10^{-12} N
2. Two objects of equal mass are separated by 10 mm. They attract each other with a force of 1.34 N. What is the mass of each object?
   $G = 6{,}7 \times 10^{-11}$ N m^2/kg^2.
   Answer: m = 1 414.2 ….. m = 1.414×10^3

3. Determine the force of attraction between the Earth and a person with a mass of 40 kg, knowing that the radius of the Earth is 6.371×10^3 m; and assuming the Earth is a perfect sphere and all of its mass is concentrated in its nucleus.
   Answer: 3.358×10^8 N