FORCES AND MASS

"Nothing happens until something moves."
— **Albert Einstein**

Language box

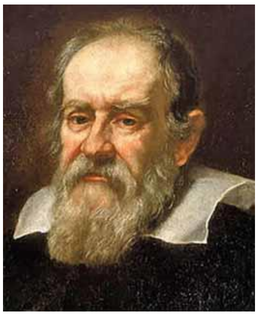
mass /-es
force /-s
contact / non-contact forces
vector /-s
newton /-s
axis, axes (pl.)
gravitational force / gravity
force system /-s
elastic
plastic

Mass is the amount of matter or 'stuff' something is made of.

The SI unit for mass is the **kilogram** (**kg**) it is the only SI unit we use where the 'base' unit has a prefix (the gram used to be used, but it is too small for everyday use).

Force is impossible to define; we have to define a force by what it does, so we say a force is a **push**, **pull** or **twist**. (The 'Force' is something else, not covered by this course)

Galileo Galilei (1564-1642) arguably the first 'real' scientist. As well as the work he did on the solar system we looked at in Year 7, he first defined **acceleration** (rate of change of velocity), and by doing experiments with balls and ramps, and watching pendulums swinging in mass, he identified that there was a 'retarding force' that stopped motion, he developed the principal of inertia – this is the idea that things either resist moving to begin with, or resist stopping when they are moving.



This is easiest to think of with things in water, where the friction is lower. Once a boat is moving in one direction, you need to either push in the opposite direction to stop it, or leave a large distance.

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 method of experimentation still used today. Applying his scientific method, Newton formulated a unified system of laws, which could be applied to all everyday phenomena, and used to make exact predictions.
Newton published his works in two books, namely "Opticks" and "Principia."

Newton's 1st Law of Motion – Law of Inertia

Every object in a state of uniform motion tends to remain in that state of motion unless an external force is applied to it.

This means that something will continue moving at a constant velocity, or will remain at rest (still, without moving) unless an external force acts on it.

Newton's 2nd Law of Motion – Law of Dynamics

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:

Or better known as:

$$\vec{F} = m\vec{a}$$

Where **F** is the **force**, measured in newtons ($1N = 1kgms^{-2}$); **mass** is measured in kg and **acceleration** in ms^{-2}. F and a, are **vector** quantities - they have a magnitude and a direction.

Newton's 3^{rd} Law of Motion – Law of Reciprocal Actions

All forces in the universe occur in equal but oppositely directed pairs; whenever one body exerts force upon a second body, the second body exerts an equal and opposite force upon the first body.

This is a complicated idea, essentially when a push or pull is exerted on something; it pushes or pulls back with exactly the same force. When you sit down, the seat pushes back up on you with exactly the same force as your weight, as long as the seat doesn't break.

Hooke's Law

Hooke's law establishes that the elongation produced on a body is proportional to the force exerted on it.

$$F = kx$$

where *x* represents how much the body has stretched or shrunk, and *k* is the elastic constant of the body.

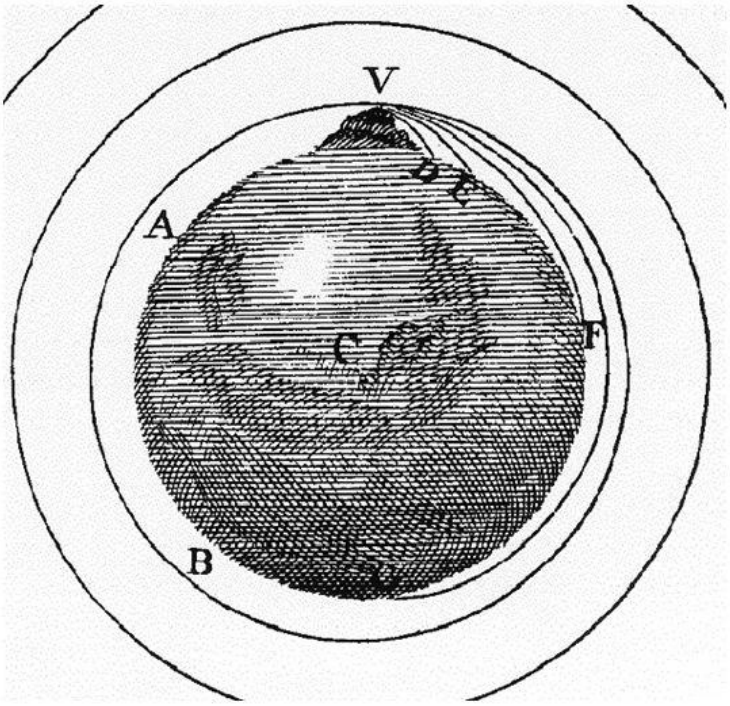
This means that when you add mass to a spring in equal quantities, it will extend by equal amounts – the k, the spring constant – will be different for different springs.

Gravity

Newton spent a large proportion of his early life on a farm, and he hated farming. He had been studying at Cambridge University but an outbreak of the plague meant he had to stay away from large gatherings of people in case he caught the fatal disease. For two years he lived on his step father's farm and it is thought that during this time he watched the simple act of an apple falling, and then thought about what was happening.

Newton thought about why the apple fell, and why when we throw things up they fall. He posited that if he could throw the apple hard enough it would go into orbit – or keep trying to 'fall' but run out of floor.

Newton's gravity



Throwing a ball fast enough puts it into orbit. The same argument explains why the Moon orbits the Earth. This was the revelation that came to Newton under the apple tree.

From Newton's Principia, 1615

In the diagram above, if you stand on a tall mountain 'V' and throw a ball, it could land at 'D', harder it would land at 'E', 'F' or 'G' but if you threw with enough push, it would not land, it would be in 'freefall'.

Newton then made the link between this and the moon in 'freefall' around Earth, and then of the Earth in 'freefall' around the Sun.

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

“The gravitational interaction between two bodies can be expressed through a force which 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):

$$\mathbf{G = 6,67 \cdot 10^{-11}\ N \cdot m^2/kg^2}$$

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

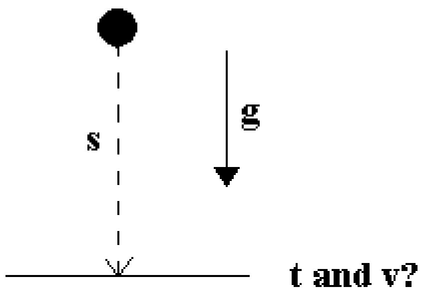
Thus, if we have an object on the surface of the Earth, the distance between the object and the centre of the Earth is equal to the radius of the planet Earth (r = 6370 km)
In this case, the equation will be the following:

$F = G \cdot \frac{M_1 \cdot m_2}{r^2}$, 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.

Free Fall

Free fall 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 body fall (*u = 0*) from a determined height (s), we can calculate the time it takes to fall and the velocity(v) with which it reaches the floor:



Weight

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

$$\boxed{F = m \cdot a} \quad \Rightarrow \quad \boxed{F_w = m \cdot g}$$

From Newton's second law we obtain the formula for weight.

Characteristics of weight:

a) axis: the line which passes through the centre of gravity of a body and the centre of the planet Earth.
b) direction: towards the centre of the Earth.
c) origin: the centre of gravity of the body.
d) intensity or magnitude: depends on the distance to the centre of the Earth.

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