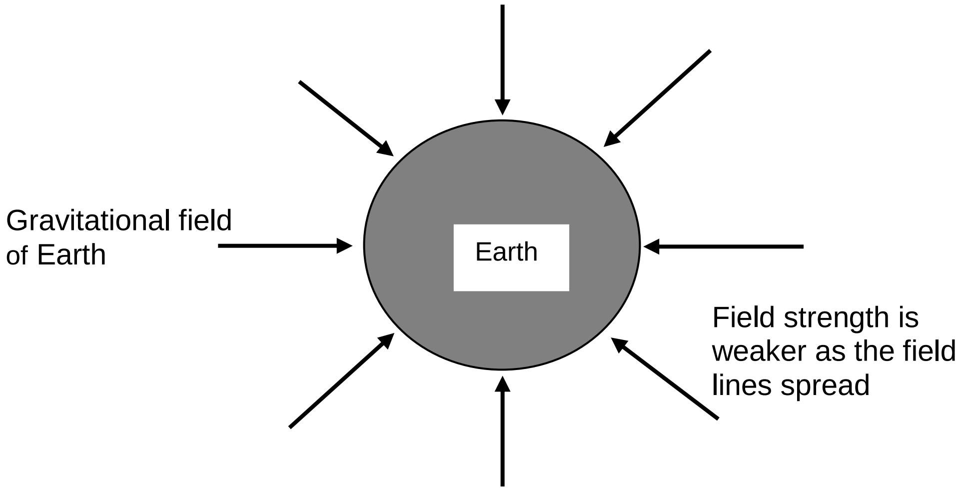
How Do Things Move Without Contact?

Reference: Heinemann Physics 12 4th Edition Chapters 1 – 3 Pages 1 – 106

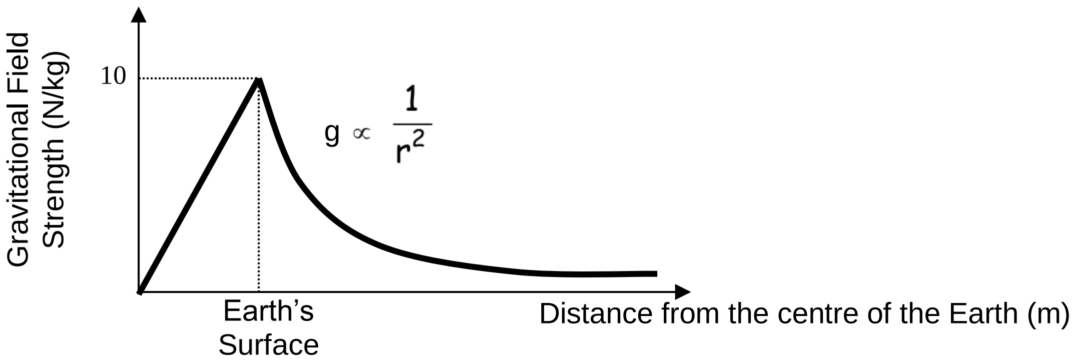
Physics with Synno – Move Without Contact – Lesson 1

G.1 Gravitational fields

For a body on, or above, the surface of the Earth, the mass of the Earth may be considered to be concentrated at its centre. The formula for the gravitational field is found by dividing the gravitational force by the mass of the smaller object.



Any object that is falling freely through a gravitational field will fall with an acceleration equal to the gravitational field strength at the point. At the surface of the Earth, the gravitational field strength, g, is 9.8 N kg^{-1}, it becomes weaker further from the Earth.

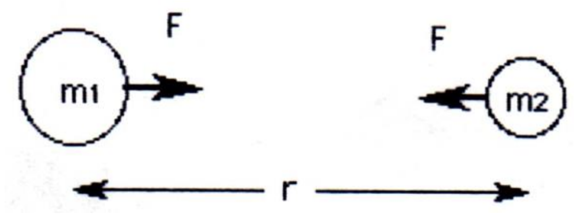


G.1.1 NEWTON'S LAW OF UNIVERSAL GRAVITATION

Video: Newton's Universal Law of Gravitation - Science in a Minute

Using his own work and that of Johannes Kepler, Sir Isaac Newton proposed that there was a force of attraction between all objects, simply because they had mass. Furthermore he proposed that the force of attraction was directly proportional to the mass of each object and inversely proportional to the square of the distance between them.
Newton called this the force of universal gravitation, and is given by:

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



where F is the magnitude of the gravitational force.

where	F	is the magnitude of the gravitational force.
	m_1, m_2	are the masses involved.
	r	is the distance between the centres of the masses.
	G	is a constant.

The constant involved is the same for all masses.
It is called the Universal Gravitational Constant.
It has a value of 6.67×10^{-11} N m^2 Kg^{-2}

Example.
Consider two people standing 1 m apart. One has a mass of 65 Kg and the other 85 Kg.
Calculate the force of attraction between them.

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

$G = 6.67 \times 10^{-11}$ N m^2 Kg^{-2} $\quad r = 1$ m

$m_1 = 65$ Kg $\quad m_2 = 85$ kg

$$F = \frac{6.67 \times 10^{-11} \times 65 \times 85}{1^2}$$

$= 3.69 \times 10^{-7}$ N (hardly a very significant force)

Determine the gravitational force that acts on a 1200 kg space probe when it is 4000 km above the surface of Mars. The radius of Mars is 3400 km and it has a mass of 6.37×10^{23}.

Radius of orbit = 3400 + 4000 = 7400 km
= 7,400,000 m
= 7.4×10^6 m

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

$$F = \frac{6.67 \times 10^{-11} \times 6.37 \times 10^{23} \times 1200}{(7.4 \times 10^6)^2}$$

$$F = 913\ N$$

G.1.1 Weight, Apparent Weight and Weightlessness

G.1.1.1 Weight

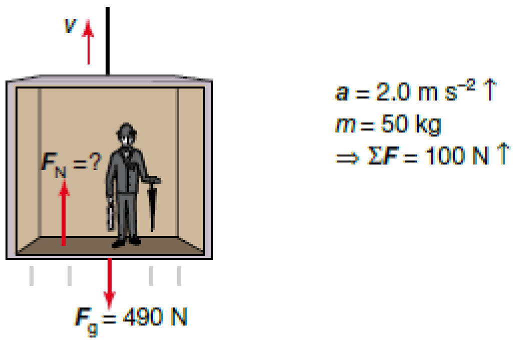
Remember from Unit 2 that weight is another name for the gravitational force acting on an object near the Earth's surface.

$$W = F_g = m\, g$$

G.1.1.2 Apparent Weight

When riding a lift as it starts to move upwards you feel more force on your legs. On the other hand when the lift starts to move downwards your feel less force in your legs. This sensation is referred to as apparent weight i.e. what your weight appears to be.
The apparent weight of a body is equal to the size of the normal force, $\mathbf{F}_N$, that acts on the body.

Example
James, of mass 50 kg, is in a lift that is accelerating upwards at 2.0 m s^{-2}.
 a What is James's mass as the lift accelerates upwards?
 b What is James's weight as the lift accelerates upwards?
 c Calculate James's apparent weight as the lift accelerates upwards.



Sol^n

a James's mass is 50 kg.

b James's weight is: $\boldsymbol{W} = m\boldsymbol{g} = 50 \times 9.8 = 490$ N

c His apparent weight is given by the normal force that the floor exerts on him.

$\boldsymbol{a} = 2.0$ m s^{-2} up, $m = 50$ kg

$\Sigma\boldsymbol{F} = m\boldsymbol{a} = 50 \times 2.0 = 100$ N $\uparrow$

$\boldsymbol{F}_N + \boldsymbol{W} = 100$ N $\uparrow$

$\boldsymbol{F}_N - 490 = 100$

$\boldsymbol{F}_N = 100 + 490 = 590$ N $\uparrow$

G.1.2 Gravitational Field

Gravitational field is the gravitational equivalent of a magnetic field. Thus any region where there is a gravitational effect there is a gravitational field.
Gravitational field has a direction, it is in the same direction as the gravitational force. On Earth it is towards the centre of the Earth.
The strength of the gravitational field is defined as the gravitational force per unit mass:

i.e. $g = \frac{F}{m}$

Consider two masses M and m. Let us calculate the gravitational field experienced by m.
The force on mass m is:

$$F = \frac{G\,M\,m}{r^2}$$

The gravitational field strength is:

$$g = \frac{G\,M\,m}{r^2} \div m$$

$$\therefore \quad g = \frac{G\,M}{r^2}$$

Example.

What is the gravitational field strength 100 km above the surface of the moon.
Mass of Moon is 7.34×10^{22} Kg, Radius of Moon is 1.74×10^{6} m.

$G = 6.67 \times 10^{-11}$

$M = 7.34 \times 10^{22}$

$r = (1.74 \times 10^{6} + 100000) = 1.84 \times 10^{6})$

$$g = \frac{6.67 \times 10^{-11} \times 7.34 \times 10^{22}}{(1.84 \times 10^{6})^2}$$

$= 1.45$ N Kg^{-1}

Another handy thing to keep in mind is that in terms of the gravitational field, the strength of the force varies inversely with the distance between the objects squared.

$$F \propto \frac{M}{r^2}$$

Where F is the force, M is the mass of the central body, r is the distance between the centers.

This is referred to as the inverse square law.

G.1.2.1 Weightlessness

Video: Weightless

The dictionary definition of weightless is to have no weight. Since weight is the force due to gravity, the object must be in a region where there is no gravitational field. Is there such a place?

$$g = \frac{GM}{r^2}$$

as $r \to \infty$, $g \to 0$

So it would appear that it is not possible to be truly weightless.
When we refer to weightlessness we are referring to a sensation. When you are in a lift and it starts to go down you feel as though you have become lighter, you felt less force through your feet. If the lift were to fall with an acceleration of g, you would feel no force through your feet. This is the sensation known as weightlessness.
An astronaut feels this sensation when in a space ship, since both he/she and the space ship are falling at the same rate.

- Satellites are in free fall around the body they orbit.
- Astronauts inside orbiting satellites are also in free fall.
- The sensation of weight depends on the size of the normal reaction force.
- In free fall the normal reaction force is zero.
- Astronauts have the sensation of weightlessness.

In summary

True weightlessness occurs when an object is in a region with no gravitational field.

Apparent weightlessness occurs when the normal reaction force is zero, i.e. when falling with an acceleration equal to the gravitational field strength.

There was a question about this concept in 2018

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