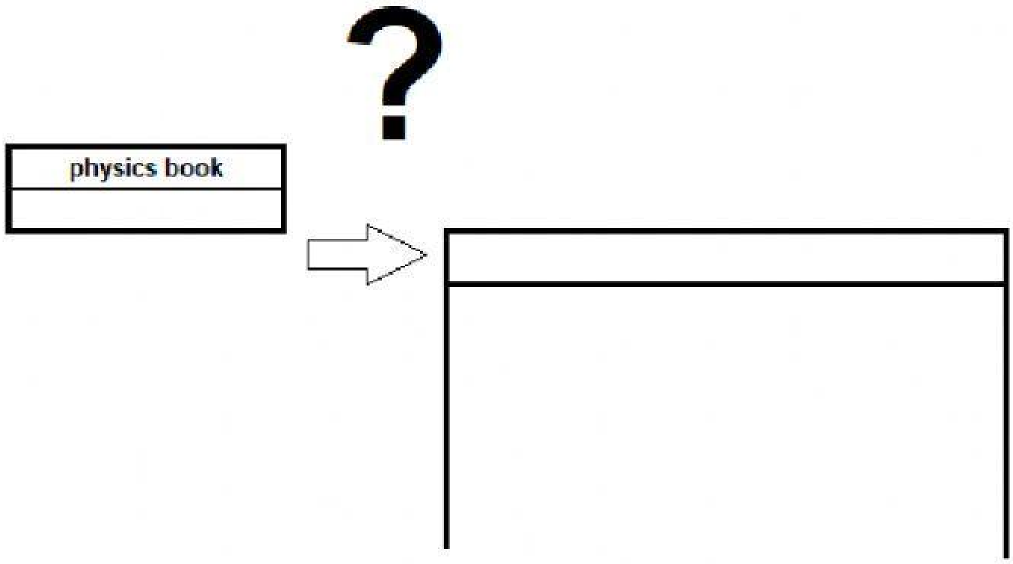
Newton's law of universal gravitation

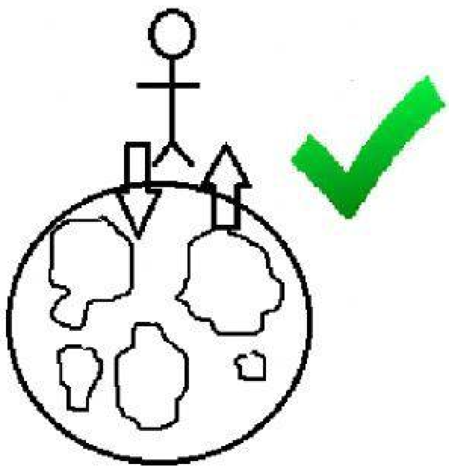
Newton determined that every object in the universe attracts every other object with a force.

But that seems untrue…..

My book isn't attracted to my desk and my water bottle isn't attracted to the wall.



Yet my body is attracted to the earth (gravitational force). When I jump up, I get pulled straight back down to earth. Why are these contradicting things happening?



It seems that some things are attracted to each other and others are not.

It is not actually a contradiction, because there are some stipulations about this attractive force.

Newton determined that the force of attraction between 2 objects is directly proportional to the product of their **masses** and inversely proportional to the square of the distance between their centres. (Does this remind you of another law?)

Coulombs law – but here they speak about the force of attraction or repulsion between charges objects and the force is directly proportional to the product of their **charges.**

DEFINITION: *Coulomb's law*

Coulomb's law states that the magnitude of the electrostatic force between two poin charges is directly proportional to the product of the magnitudes of the charges an inversely proportional to the square of the distance between them.

$$F = \frac{kQ_1Q_2}{r^2},$$

Thus Newton's law about objects attracting each other states that the magnitude of the product of the masses is important.

The greater the product of the masses – the larger the attractive force. Force is directly proportional to the product of the masses.

$F \propto m_1.m_2$

And the size (magnitude) of the force is inversely proportional to the square of the distance between the objects' centres.

$F \propto \frac{1}{r^2}$

So your book IS in fact attracted to your desk, but the product of their masses is SO small that that force is negligible.

For example the product of their masses might only be= 4kg x 50 kg

= 200

Whereas – the earth attracts you with a force that is large, because the product of your mass and the earth's mass is a VERY large number {the earth's mass is $5{,}98 \times 10^{24}$kg!}

Then the product of your masses might be = $5{,}98 \times 10^{24}$kg x 80

= $4{,}78 \times 10^{26}$

And by the way – if the earth is attracting you with this force, then you are also attracting the earth with this **SAME** force.

Which other Newton's law is the explanation for this above statement?

(just say the number of the law, i.e. one, two or three.

____

Thus we can put these proportionalities together and get the following:

$$F \propto \frac{m1.m2}{r^2}$$

Now remember that we can't just replace a proportionality sign with an equal sign- we need to insert a constant into the equation.

In this case the constant is called the universal gravitational constant (G) and it is equal to $6{,}67 \times 10^{-11}$

$F = \frac{G.m1.m2}{r^2}$

F – gravitational force (N)

G – universal gravitational constant ($6{,}67 \times 10^{-11} N.m^2.kg^{-2}$)

m – mass of the object (kg)

r – distance between the centre of the objects (m)

Let's do some examples of using this formula

Calculate the gravitational force between the following:

1. An object with a mass of 2000 kg and another with a mass of 4000kg, and their centre's are 40 cm apart.

$F = \frac{G.m1.m2}{r^2}$

$F = \frac{[6{,}67\ x\ 10^{-11}(2000)(4000)]}{(40 \div 100)^2}$

If your calculator is doing funny things – it's probably a good idea to put the entire top of the equation into a bracket

= 0,003335 {if an answer is this small, then rather put it into scientific notation.}

= $3{,}34 \times 10^{-3}$ N attractive {unlike the electrostatic force that can be attractive or repulsive, this force is **ALWAYS** attractive}

2. Two objects each with a mass of 100 kg and with their centres 300 mm apart.

$F = \frac{G.m1.m2}{r^2}$

$F = \frac{[6{,}67\ x\ 10^{-11}(100)(100)]}{(300 \div 1000)^2}$

= _____ x 10^{-6} N attractive

3. An object with a mass of 80 kg on the surface of the earth.

$$F = \frac{G.m1.m2}{r^2}$$

$$F = \frac{[6{,}67 \times 10^{-11}(80)(5{,}98 \times 10^{24})]}{(6{,}38 \times 10^6)^2}$$

Look at how much bigger this value is of the attractive force of a planet and an object

= ____x 10__ N or ______ N {It's better to write really big values in decimal notation – because then you are not 'cutting off' so many decimals at the end}

4. Calculate the distance between 2 objects of masses 250 kg and 1000 kg respectively if the attractive force between them is 20N.

$$F = \frac{G.m1.m2}{r^2}$$

DO NOT manipulate the formula first and then substitute. Rather substitute into the original formula and then manipulate after

$$\frac{20}{1} = \frac{6{,}67 \times 10^{-11}.(250)(1000)}{r^2}$$ {cross multiply}

$20.r^2 = (1)\ (6{,}67 \times 10^{-11})(250)(1000)$

*then divide each side by 20

$$\frac{20r^2}{20} = \frac{6{,}67 \times 10^{-11}.(250)(1000)}{20}$$

$\sqrt{r^2} = \sqrt{8{,}3375 \times 10^{-7}}$

r = _____ x 10— m

5. Calculate the mass of an unknown object, if the attractive force between that object and a 5000 kg object is 400 N and their centres are 30 cm apart.

$$F = \frac{G.m1.m2}{r^2}$$

$\frac{400}{1} = \frac{6,67 \ x\ 10^{-11}.m1.(5000)}{(30 \div 100)^2}$

_______ = (6,67 x10^{-11}) (m_1) (5000)

*then divide both sides by 6,67x 10^{-11}(5000)

$\frac{\_\_\_\_\_\_\_\_\_\_\_\_}{6,67\ x\ 10^{-11}(5000)} = \frac{(6,67\ x10-11)\ (m1)\ (5000)}{6,67\ x\ 10^{-11}(5000)}$

m_1 = ____________ kg {leave in decimal notation and round to 2 decimals}

5. Two objects, with the same mass, are separated by a distance of 1m and the attractive force between them is 0,0004 N. Calculate the unknown masses.

F = $\frac{G.m1.m2}{r^2}$

0,0004 = $\frac{[6,67\ x\ 10^{-11}(m)(m)]}{(1)^2}$

Just careful – m x m is equal to m^2, not 2m ☺

*cross multiply

_____________ = 6,67 x10^{-11} . m^2

*then divide both sides by 6,67 x 10^{-11}

m = √

m = _______ kg {remember to write bigger answers in decimal (not scientific) notation and to round off to 2 decimal places}

Exercise 1:

1. Two bodies of mass 6 000 kg and 8 000 kg are separated by a distance of 100 m.

1.1 Calculate the magnitude of the gravitational force of attraction that they exert on each other

$$F = \frac{G.m1.m2}{r^2}$$

$$F = \frac{[6{,}67\ x\ 10^{-11}(\qquad)(\qquad)]}{(\qquad)^2}$$

$= \_\_\_\_\_\_ \text{ x } 10^{\_\_\_} \ \_\_\_\_\_ \ \_\_\_\_\_\_\_\_\_\_$

Exponent

Unit

Direction

{always round answer to 2 decimal places}

2. Two bodies of mass 2×10^4 kg and 8×10^{11} kg are separated by a distance of 100 km.

2.1 Calculate the magnitude of the gravitational force of attraction that the first body exerts on the second.

$$F = \frac{G.m1.m2}{r^2}$$

$$F = \frac{[6{,}67\ x\ 10^{-11}(\_\_x\_\_\ )(\_\_x\ \_\_\ )]}{(100\ \ x\_\_\_\_)}$$

$= \_\_\_\_\_\_ \text{ x } 10^{\_\_\_} \ \_\_\_\_\_ \ \_\_\_\_\_\_\_\_\_\_$

2.2. What is the magnitude of the force that the second body exerts on the first?

$= \_\_\_\_\_\_ \text{ x } 10^{\_\_\_} \ \_\_\_\_\_$

The following constants will always be given on the data sheet:

NAME/*NAAM*	SYMBOL/*SIMBOOL*	VALUE/*WAARDE*
Acceleration due to gravity *Swaartekragversnelling*	g	$9,8 \text{ m}\cdot\text{s}^{-2}$
Universal gravitational constant *Universele gravitasiekonstant*	G	$6,67 \times 10^{-11} \text{ N}\cdot\text{m}^2\cdot\text{kg}^{-2}$
Radius of the Earth *Radius van die Aarde*	R_E	$6,38 \times 10^6$ m
Mass of the Earth *Massa van die Aarde*	M_E	$5,98 \times 10^{24}$ kg

3. A satellite has a mass of $1,5 \times 10^3$ kg. It orbits the Earth at a distance of $1,25 \times 10^7$ m from the centre of the Earth, which has a mass of $5,98 \times 10^{24}$ kg.

3.1 Calculate the gravitational force that the Earth exerts on the satellite.

$$F = \frac{G.m1.m2}{r^2}$$

$$F = \frac{[6{,}67\ x\ 10^{-11}(\_\_\_x\ 10\quad)(\_\_\_x\ 10\quad)]}{(\quad x\ 10\quad)}$$

= ______ x 10___ ____ towards the earth (since the question focused on the force on the satellite)

3.2 Decide whether the force exerted by the satellite on the Earth will be greater than, smaller than or the same as the force exerted by the Earth on the satellite. {only state: greater than, smaller than or equal to}

_______ _________

3.3 Calculate the weight (force of gravity) on a 70 kg person on the earth.

Fg = ______ _____ towards the earth

There is another formula in this Newton section, which you have used many times now

Fg = m.g

When the object is **<u>on the earth</u>** the gravitational acceleration will be $9{,}8 m.s^{-2}$

3. Calculate the gravitational force (weight) between an object with a mass of 80 kg on the surface of the earth.

$$F = \frac{G.m1.m2}{r^2}$$

$$F = \frac{[6{,}67 \ x\ 10^{-11}(\quad)(\quad x\ 10^{-})]}{(\quad x\ 10^{6})^2}$$

= ______x 10– N or N

Now you could actually have done this question using

Fg = m.g

= ___ (___)

= _____ N {it can give you a slightly different answer though – but that is fine}

However you can only use this formula if you are given the g (gravitational acceleration) value on that planet. **On earth the g value is always $9{,}8 m.s^{-2}$**

But on mars for example it is $3.72076 m.s^{-2}$ {but they could always give a slightly different value in an exam}

Calculate the gravitational force (weight) of the following, using both formulae, so