Nelson Text: p82-95

Updated: April 2020
Course: SPH 3U1
Unit: MECHANICS

Lesson 4: Gravity

I normally start this lesson with a pretest: students get some paper, write down the answers to these questions and then hand them in (with no names).
We then discuss how the various ideas can be tested. Why might people think that particular idea?

(1) What is gravity? (2) What causes gravity? (3) What determines how fast things fall?

Common misconceptions:
** the atmosphere causes gravity. Why? In space there is no air and there is no gravity ! So, voila! But the moon feels the earth's gravity, so there is gravity in space.*
** the centre of the earth causes gravity? Why? it's a mysterious hot mess down there. Very dense molten metal. BUT the moon also has gravity, as does the sun, so it's not the earth's core that causes it.*
** the rotation of the earth causes gravity. If the earth stopped rotating we'd all fly off. No. This is totally wrong. The people who think this have it backwards. If the earth rotated faster we'd fly off. I don't know why people think this.*

Definition:

Gravity is caused by matter. All matter has mass. All mass is attracted to all other mass.
We call this attractive force "gravity".

What makes gravity stronger? weaker?
Gravity is stronger when masses are bigger and weaker when they are further apart.
Which is bigger? the earth or the moon? [*How do you know?*]
we weigh more on earth than on the moon.

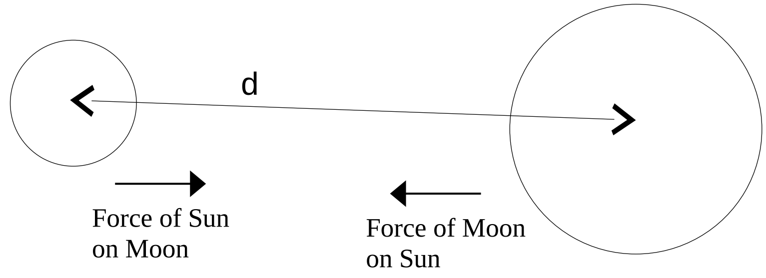
What are tides caused by? [*How do you know?*]
Jupiter is much bigger than the moon [*how do you know?*], but much farther away.
it doesn't have enough influence to cause tides.

Sir Isaac Newton investigated these things, and ***discovered*** the **Law of Universal Gravitation:**

$F_g = \frac{G m_1 m_2}{d^2}$ This tells us the force of gravity between two masses m_1 and m_2 that are separated by a distance d (sometimes also called r).
Note that d is measured from the centre of each mass and the masses are spheres.

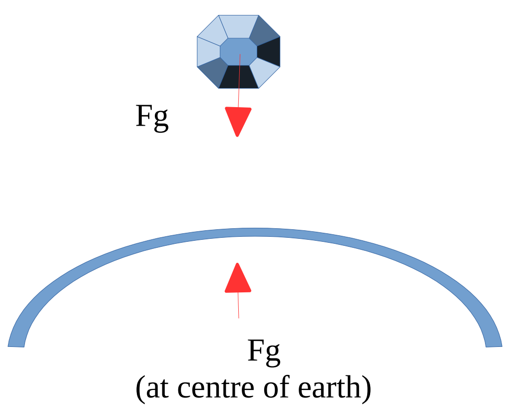
G is the universal gravitational constant, a fundamental constant of the universe (like the speed of light).
$G = 6.67 \times 10^{-11}$ *What do you notice about this number? It's incredibly small.*
What units must it have? Nm^2/kg^2
Note that it is a capital G, not lowercase. Lowercase g is something else

This is not a vector equation. So, in which <u>direction</u> does gravity act? It pulls things towards each other.



Since G is so small you need a huge mass, planet sized, before the force of gravity becomes large enough to notice. This is why when you walk into your room, all the objects in your room don't get attracted to you and fly up and stick to you.

Example: What is the force of gravity between the earth and a 100 kg satellite 200 km above the earth’s surface? **<u>Draw a FBD first</u>**. (*Indicate that the force of gravity on each one is equal and opposite) Because these diagrams are so straightforward, you don't need to draw FBD for these simple sort of gravity problems.*



<u>Notation:</u>
9.6 E 7 means 9.6×10^{7}
1.2 E -5 means 1.2×10^{-5}

$$F_g = \frac{Gm_1 m_2}{d^2}$$

NOTE that the altitude of 200km is the distance above the earth's surface. We have to add in radius of the earth which is about 6370 km. Also, everything must be in metres.

$$Fg = \frac{G\,(\text{mass of earth})\,(\text{mass of satellite})}{\text{distance}^2}$$

$$= \frac{(6.67\text{ E-11 Nm}^2/\text{kg}^2)\,(5.98\text{E24 kg})\,(100\text{ kg})}{(6570{,}000\text{ m})^2}$$

= 924 N. ← please make sure that you get the same answer

What is the force of gravity on a mass **m** that is resting on the earth’s surface?

$$F_g = \frac{(6.67\text{ E-11 Nm}^2/\text{kg}^2)\,(5.98\text{E24 kg})\,(\mathbf{m})}{(6370{,}000\text{ m})^2}$$

= m (9.8 N/kg)

The force of gravity on a mass **m** at the earth's surface is **m** x (9.8 N/kg) . We call this number 'g', the **gravitational field intensity**. (9.8 N/kg only as long as you don't change m_e or r_e)

$F_g = mg$ This is the formula for the force of gravity on the earth's surface.

It's a LOT faster than using the general formula that works anywhere in the universe. $F_g = \frac{Gm_1 m_2}{d^2}$

The force of gravity on the 100kg satellite on the earth's surface is F_g = mg = 980N. This is a bit more than the 924N that we calculated because that is not at the earth's surface, and gravity gets weaker with distance. The force of gravity is largest at the surface of the planet and it gets smaller, going to zero, as you get further and further away.

- On other planets, 'g' will be different. It's about 1.6 N/kg on the moon.
- **The units N/kg are the same as m/s^2** , however we can't just write -9.8 m/s^2 because an object that is not accelerating, but at rest on a table still experiences a force of gravity. It only accelerates at -9.8m/s^2 once it is dropped.

Demonstration:
Which will fall faster, this sheet of paper squished into a ball or this textbook? Why?
Drop both. What did you see?
What determines how fast something falls?

(i) the force of gravity, (ii) air resistance (this depends on shape, mass, speed, and type of fluid).

For something falling in a vacuum, the only force on it is Fg. Fnet = Fg, or ma = mg. $a_g = g$.

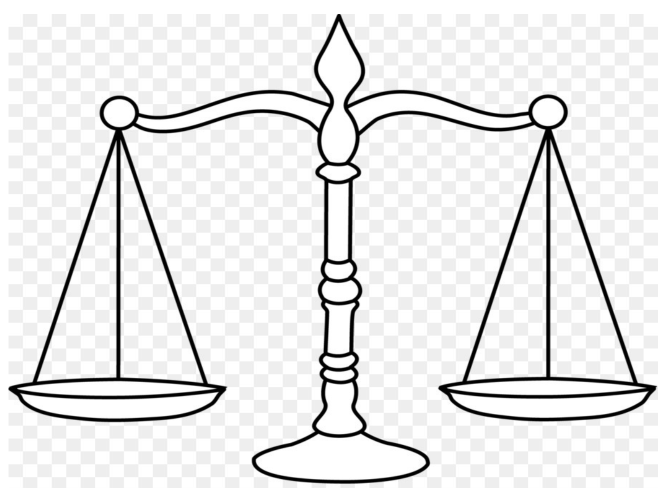
So the acceleration due to gravity on <u>any mass</u> near the surface of the earth is -9.8 m/s^2 !!!
As long as we ignore air resistance, which we can for most dense objects.

This means that all masses accelerate at the same rate the mass does not matter! This is why we did not ever include the mass in our equations of motion ($d = \frac{1}{2} at^2 + v_1 t + d_1$ and $v = at + v_1$).
Any object dropped from height h will reach the ground at the same time, no matter the mass (ignoring air)
(Use kinematic equations to figure it out: $h = 1/2gt^2$ so t = 2h/g .)

What is the difference between **mass and weight?**

Mass is

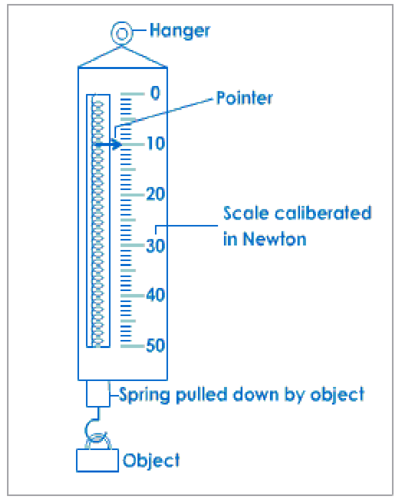
a measure of the amount and type of matter in an object.
It doesn't change unless you change the object.
Units: kilograms.
Measured on a balance.
You can see that if you put a 500g mass on the left and a 500g rock on the right pan, the balance will stay balanced on earth, on the moon, and on any planet, no matter what the gravity.



Weight is

the same as the force of gravity on an object. W = |Fg|.
No gravity = no weight! but you still have mass.
Units: Newtons. (The imperial unit is pounds)
Measured on a spring scale.

You can see that the object is attached to the spring, and that it's gravity that pulls it down. The more gravity the more it is pulled down. So a spring scale measures the force of gravity and not mass.



(I'll make another page about gravity and orbits later)

Homework:

Please do any of the Nelson questions that you can, that you find interesting, that are not obvious to you. You don't have to do all of them.
Please also do II, III, IV.

I. Nelson: p85ff #4, 6, 10, p90#10, p93#4 p95#6 — http://quarkphysics.ca/Nelson11/ (Section 3.1 and 3.2)

II. Calculate the force of gravitational attraction between a boy and a girl, each massing 60 kg if they are 1m apart. (Assuming that the non-spherical shape can be ignored)
What about if they are 1 mm apart?
It's impossible: (i) masses not concentrated at one point
(ii) cannot get centres of mass 1 mm apart.

III. a) List two ways to reduce the weight of an object.
b) List one way to reduce the mass of an object.

IV. An ion drive on a spacecraft can produce a thrust of 200 milliNewtons.
a) What is the acceleration that this provides on a 70kg spacecraft?
b) If this is the only force on the space craft, how fast will the spacecraft be travelling after 1 day? after 1 week? after 1 month?

V. Challenge problem!
So, the force of gravity is equal and opposite on both objects. If you jump down from a 2m high ledge, you fall down because the earth's gravity pulls you down. But your equal and opposite gravitational force would pull the earth up. How much does the earth move up while you move down the 2 m ?
To solve this, you'll need equations of motion too, and you'll need to find the time that you are falling in the air. I'll go over the answers in a few days.

Extra: Also need to discuss inverse square laws. *see page 91*