A Peek Through The Metric System

Introducing the metric system gives an excellent opportunity to look at basic physics. We'll only deal with the measuring of space, mass and force, and leave time alone.

1. Special names for 10-steps

Even though the words "metric system" refer to the metre, the big advantage of this system is not the choice of the metre, but the systematic use of ten multiples. The three basic increment steps are thus, 10, 100, 1000, or looking in reverse, 10-th, 100-th, 1000-th. Special names are given for five of these as:
10 = deka
1000 = kilo
10-th = deci
100-th = centi
1000-th = milli

2. Space

The unit of length is metre. The exact metre can be defined from the size of the earth or by a pendulum that has one second swing time. A copy of an exact rod is kept in Paris. Easiest is to remember that an average adult is about 1.7 to 1.8 metre tall, so a metre is about up to our belly. An arm length or a big step is also about this long.

The millimetre, centimetre and decimetre are therefore the lengths of a pinhead, a finger and a palm. For the multiples, only the kilometre is used. Since this is a thousand metre and an average walking person takes about two small steps in a second, thus a kilometre takes two thousand steps or a thousand seconds. That's about 15 minutes or a quarter of an hour. To put it an other way, in a full hour, we can walk four kilometres. An other way of saying this is that our walking speed is 4 kilometre per hour or 4 km/h. In cars, we see the km/h speed meter go even beyond 100. When airplanes take off, they need a few hundred km/h speed. Passenger airplanes will never go beyond 1000 km/h speed because it is about the speed of sound and crossing this is difficult. This is also called mach 1 speed, and military jets go beyond this, even double it to mach 2. Rockets go even faster. Light goes about a million times faster than sound so with about 1000 , 000 , 000 km/h = 1 billion km/h. In an hour, there are 60 x 60 = 3600 seconds, so light in a second goes only 3600-th of a billion kilometre or more precisely, 330 , 000 km. An other even better way to see how big the speed of light or how big the solar system is to realize that from the sun to the earth, light takes 8 minutes to reach.

From the length, we can measure areas by using squares. One square centimetre = cm^2 is the area of a finger nail. One square metre = m^2 is an average table.

Volumes are measured by cubes.
cm^3 = cubic centimetre = cc = a small dice.
m^3 = cubic metre = a big TV box.

The most practical size is dm^3 = cubic decimetre = a box we can hold with our fingers. This volume has a special name as litre. Half of a two litre milk bottle is exactly a cube with decimetre size which explains why it was a two litre bottle.

The 10-steps of the metric system lengths become 1000-s when we look at volumes. Indeed, in a cc, 10 x 10 x 10 = 1000 mm^3 can fit. Similarly in a dm^3 = litre 1000 cc fit. And, in a m^3 again 1000 dm^3 = litre:

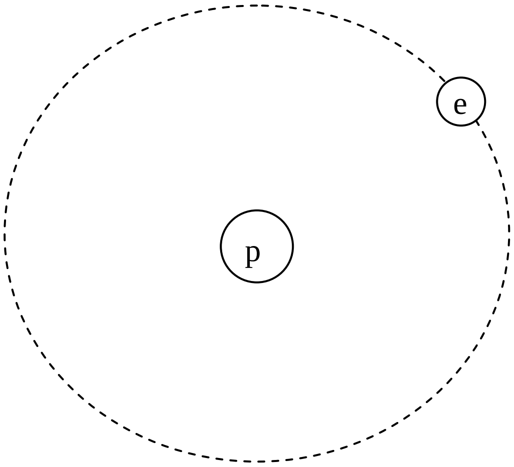
$$\text{mm}^3 \underbrace{\qquad\qquad\qquad}_{1000} \text{cm}^3 = \text{cc} \underbrace{\qquad\qquad\qquad}_{1000} \text{dm}^3 = \text{litre} \underbrace{\qquad\qquad\qquad}_{1000} \text{m}^3$$

This fits very well into the custom that big numbers are named in thousand steps:
ten = 10 , hundred = 100 , thousand = 1000
ten thousand = 10 , 000 , hundred thousand = 100 , 000.
But, “thousand thousand” = 1000 , 000 = million. Similarly,
ten million = 10 , 000 , 000 , hundred million = 100 , 000 , 000
But, “thousand million” = 1000 , 000 , 000 = billion. And again,
ten billion = 10 , 000 , 000 , 000 , hundred billion = 100 , 000 , 000 , 000
But, “thousand billion” = 1000 , 000 , 000 , 000 = trillion.
Thus, we know at once that 1 m^3 is a million cc or a billion mm^3.
Engines can be measured by how big the cylinders are in total. For motorcycles, they usually give this in cc, but for cars, in litre. A small car has a 1.6 l engine which is 1600 cc and is huge for a motorcycle.

3. Matter as atoms

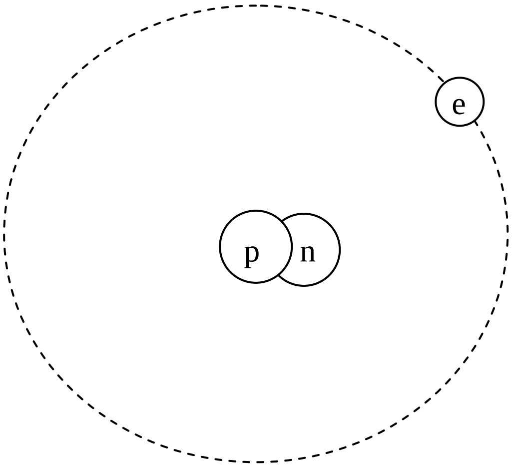
Every atom contains protons and neutrons in the center and small electrons around.
The protons are positive, the electrons are negative, the neutrons have no charge.
The same charges repel, the different ones attract. Thus, the protons attract the electrons and that’s why they stay around. They are orbiting with high speeds and that’s why they don’t fall into the protons. The electrons repel each other so they never collide. The biggest mystery of this picture is how the protons can stay together when they should repel each other. The solution is the existence of neutrons. They are continually changing into new protons while, the protons change into neutrons. This exchange force can overcome the repulsion. In a normal atom, the protons are the same in number as the electrons, so the atom is neutral to the outside. If an atom looses or gains electrons then it becomes a so called ion and then it has charge. When matters are in contact, such loss and gain of electrons is always happening. Taking off our pullover or walking on a carpet gives us electrostatic charge, which thus means simply gaining or losing a few electrons. The number of neutrons needed to keep the protons together is about the same or more as the number of protons themselves, but as the number increases, the excess of neutrons is increasing too. After about 100 protons, even double as many, that is 200 neutrons is not able to keep the protons together, thus there won’t be new atoms possible. The biggest exception to the need of neutrons is the simplest case when there is only one proton. Since it’s alone there is no repulsion, no neutron is needed. So, this simplest atom, the hydrogen, contains only one proton and one electron orbiting around it.

Hydrogen:

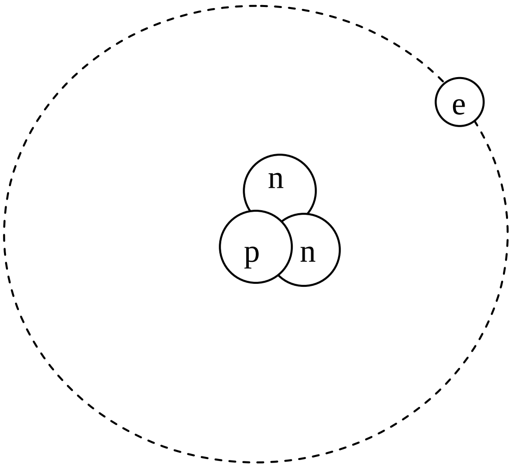


This doesn't mean that a neutron or even two can't be there:

Deuterium:

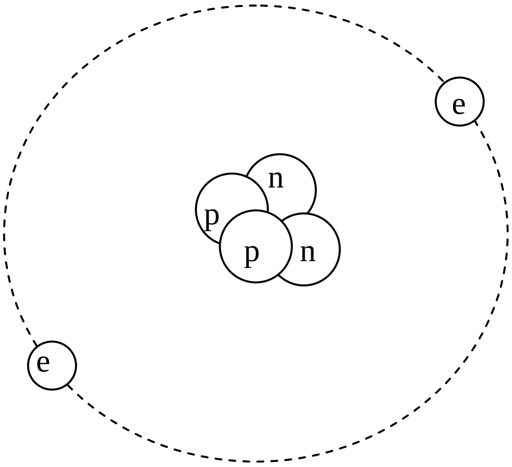


Tritium:



So the deuterium and tritium are mere variants of the hydrogen.
When they first put all the atoms in a table, then such neutron variants were not recognized yet, so they were put together in the same place. Same = iso, place = topos, thus today these are called isotopes. So the hydrogen has three isotopes, the normal and the two rare ones, deuterium and tritium.
The simplest atom that always need neutron is the one having two protons, the helium. Normally it needs two neutrons:

Helium:



This again can have more neutrons giving new isotopes, but these don't have special names, like we had for the hydrogen.
As we use more and more p , n , e, we get all possible atoms.

The different atoms are also called elements, if we look at them as real matter around us. Some are really around us, but some are hard to find. Also, when we find an element the isotopes are still mixed in it, they don’t look different. To separate the isotopes, is even harder than to separate the elements.

The main reason, the atoms are hard to be found in themselves as elements, is that they mix with each other. In fact, they not only mix, they combine too!

The combined atoms are called molecules. Even identical atoms can combine. For example, the oxygen that we need to breathe is an atom, but in the air it is found mostly as combined molecule of two oxygen atoms. So, it’s not the O that we breathe, rather the O_2 oxygen molecules.

Besides the oxygen molecules, most of the air is nitrogen molecules which we don’t use at all. The carbon dioxide molecules that animals breathe out only give less than a percent of air. The ozone that we hear so much about lately is special molecules of three oxygen atoms.

$$\text{Air} = \begin{cases} 78\ \%\ \text{Nitrogen molecules} = N_2 \\[1em] 21\ \%\ \text{Oxygen molecules} = O_2 \\[1em] 1\ \%\ \text{Other gases} \\ \qquad \text{mostly Argon} \\ \qquad \text{Carbon Dioxide} = CO_2\text{ , Ozone} = O_3 \end{cases}$$

In the air, the mixture of these are kept in constant motion because being a gas they are flying and bouncing from each other.

If we release some other gas into the air, it might mix too, but sometimes it is too light, and raises up or too heavy and sinks down. For example, helium would rise, that’s why we use it for balloons.

In a liquid, the mixing is similar. The atoms and molecules are in motion even though they don’t fly freely, so perfect mixing is possible but not always achieved. For example, if we put some sugar in water, it melts perfectly, but if we put too much, it sinks to the bottom. Oil always goes to the top, it doesn’t mix at all.

The combined atoms or molecules are also called compounds if we regard them as the matters around us. Above we saw, that in the air is CO_2 which is thus a compound. The most important compound is water, H_2O. Thus, every water molecule contains two hydrogen and one oxygen atom.

As we see, all mixtures or compounds still only contain atoms and thus protons, neutrons and electrons. Thus, the total amount of matter is simply how many of these are present. This total is the mass of a matter.

4. Measuring mass by water

The unit of mass is gram which is the total of protons, neutrons and electrons in one cc water. Obviously, one cc of air, metal or oil is not one gram because they contain less or more particles than water. In other words, their density is different.

So how can we measure the mass of other matters than water by grams?

There are two ways to compare other materials. The two methods are based on the two basic laws that affect all matters in the universe. One is inertia, the other is gravitation.

Inertia means first of all, that if something is in a motion or rest, it wants to stay the same. To be more precise a body wants to keep its speed. We don’t see this on the earth, in fact all motions stop by “themselves”, but this is an illusion. They are never in themselves, interfering outside forces are all around. Out in empty space if something flies it remains so. Here on earth the most important interference is gravitation, though this can be “eliminated” if we don’t move up and down. For example, on a flat icy surface, objects really almost keep their speeds. Of course, a little friction is still slowing them down eventually.

The tendency of an object to keep its speed has as consequence that if we try to change that speed, we have to use a force. This force we need to change the speed is not only depending on the change of the speed but also on the mass of the body. Thus, this second appearance of inertia that is the resistance to a force, is usable to measure mass. If we use a fix force like a spring to speed up a cc water with certain success that is speed change, and then an other amount of different material with the same spring and with the same success of speed change, then that matter has the same mass as the water. The change of speed is also called acceleration, even though it can be a decrease of speed, which actually should be called deceleration. This measuring masses by accelerating them is pretty complicated but easy to do in outer space.

On a planet like on earth, there is an easier way! As we mentioned, the gravitation is a disturbing effect against the first form of inertia or kept speeds. On the other hand, gravitation is useful to measure mass directly! Since gravitation, the attraction of matters is true for all kind of matter, it is basically just a combined effect of the attraction of all particles. Even inside one atom, all particles attract each other, but there this gravitation is so small, that it doesn’t attract the much bigger electric or nuclear exchange forces. Two apples on a tree, attract each other too, but even there, the gravitational effect is still too small, that’s why we don’t see the apple’s moving towards each other. Only when at least one of the objects is huge, can we see the attractions. So an apple and the earth are attracting each other visibly simply because the earth is big enough. The earth and the moon attract each other even more, because they are both huge, similarly, the sun and the earth and all planets.

If an apple and the earth attract each other equally, then why only the apple falls? It’s not true! They both fall towards each other. But as we saw above, the mass gives a resistance to any force. So the same force is on the apple and on the earth except in opposite directions, but the apple has much smaller mass and thus, starts to accelerate rapidly while the earth is big and can only change its speed much, much slower. By the time, the apple falls down the earth couldn’t even start to move towards the apple. Thus, we can ignore the earth’s motion and then indeed it seems that all objects fall. It also becomes clear why all objects fall together, regardless how heavy they are. A heavier object is merely more particles falling simultaneously. Two pencils falling next to each other don’t affect each other. If we tie them together, this doesn’t affect their fall either. A pencil in itself is just atoms tied together. In fact, every atom is just particles tied together. The common fall, doesn’t mean that heavier objects fall with the same consequences. After falling from the same height, heavier or lighter objects reach the same speed because they fell together but, their impact on the ground is different, because the heavier objects have bigger mass, their inertia is bigger. Even when a body can’t fall, its gravitational force or weight can be measured by scales. This weight is perfectly measuring the mass too and thus, the water’s mass as weight can be used to measure any other materials.

As we said, the gram is the mass of 1 cc water. This is pretty small. The mass of one m^3 of water is called a tonne, which on the other hand is too big. The logical in between size is 1 dm^3 = 1 litre which is 1000 gram = 1 kilogram.

5. Separating the force from mass

We usually measure mass by weight which is the gravitational force.

To make the theory clearer they gave special name for the force itself as pond.

So, 1 pond is the force that 1 cc water, that is 1 gram matter experiences on the earth’s surface. 1 kilo-pond is the force on 1000 cc = 1 litre water or 1 kg matter.

Gravitation depends on the distance, so a gram matter moved further away from the earth will be less heavy. Thus, on top of the Mount Everest, 1 cc water is still 1 gram, but it is not 1 pond, but a little bit less.

The other way of measuring mass was by accelerating them. That method gives a way to measure forces too by accelerating the same mass with different forces.

1 cc water, that is 1 gram matter needs 1 dyne force to change its speed by 1 cm per second in every second, or in short, to achieve a 1 cm/sec^2 acceleration. This is a very small force. If we use 1 litre = 1000 cc water instead, then obviously to get the same 1 cm/sec^2 acceleration, we need 1000 dyne. If we achieve not 1 cm/sec^2 rather, a 100 times bigger 1 m/sec^2 acceleration, then that requires 100 , 000 dyne. This has a special name as 1 newton. Thus, a newton is the force needed to accelerate a litre water or any kg of matter, so that it is speeding up in such a way that in every second its speed is increasing with 1 m/sec. On the earth a falling body is increasing its speed even much faster than this, namely it increases its speed in every second by 9.81 m/s. In other words, after 1 second, every falling body is already moving with a speed that if it would keep this speed, and not accelerate anymore, it would travel 9.81 in every second. Of course, this speed was achieved in the first second gradually, so the falling body's average speed in the first second was only half of 9.81, which is about 5. And so, the fallen distance is the 1 second traveling time multiplied by this average speed which is again about 5 metres. If we let the object fall further, after two seconds, it should reach 2 x 9.81 final speed. In the second second, the average speed was the average of 9.81 and 2 x 9.81, which is 1.5 x 9.81, so about 15 m/s. Thus, the fall under the second second is also 15 metre. Then in the next second, it will be 25 metres and so on, the odd numbers multiplied by 5 give the falling distances second by second. Galileo realized this but missed the underlying better low. The sum of the odd numbers are the square numbers: 1 + 3 = 4 , 1 + 3 + 5 = 9 , and so on. Thus, if we don't look at the distances second by second rather the total fallen distance under a t time, then it is simply 5 t^2. The big advantage of this one is that we don't have to use whole seconds. It even gives the fallen distance for t = 0.5 sec. Indeed, $d = 5 \times 0.5^2 = 1.25$ metre. Regarding the 9.81 earthly gravitation as about 10, also means that the earthly acceleration of a litre water is 10 times bigger than what 1 newton brings about and thus, 1 kilo-pond is about 10 newton.