

Science Basics

Do you ever feel bamboozled by expert colleagues, and too ashamed to ask what they mean by a gene, a teraflop or a barrel of oil? Or do you ever feel the need to get back to basics when helping with that science homework? If so, you might find the answer in this note, which includes information about:

- The Measurement System
- Conversion factors
- Derived Units
- Sound and Light
- Geology, the Earth etc.
- Atoms, radiation
- Sub-atomic particles
- Biology

The Measurement System

In principle, all physical measurements can be reduced to a combination of the following **7 SI* Base Units**:

Mole (amount of substance)
Metre (length)
Kilogram (mass)
Kelvin (temperature)
Ampere (electric current)
Candela (luminosity) &
Second (time).

*SI stands for Systeme International d'Unites

All other measurements, such as Newtons, Pascals, ohms etc can be reduced to the above units. Some examples are later in this note.

The following prefixes can also be added to the above units.

yocto	y	10^{-24}
zepto	z	10^{-21}
atto	a	10^{-18}
femto	f	10^{-15}
pico	p	10^{-12}

nano	n	10^{-9}	
micro	μ	10^{-6}	
milli	m	10^{-3}	
centi	c	10^{-2}	
deci	d	10^{-1}	
deca	da	10^1	
hecto	h	10^2	
kilo	k	10^3	- that is a thousand
mega	M	10^6	- that is a million
giga	G	10^9	- a billion
tera	T	10^{12}	- a trillion
peta	P	10^{15}	
exa	E	10^{18}	
zetta	Z	10^{21}	
yotta	Y	10^{24}	

The higher of these prefixes are increasingly often found in descriptions of computer speed, storage etc. So:-

- 1 bit is one unit of storage in a computer (i.e. a “0” or a “1”).
- A byte is 8 bytes (such as 10011001 - and contains enough information to identify, for instance, one symbol; such as a letter of the alphabet).
- A kilobyte is 1000 bytes, and so on up to a petabyte.
- A “flop” is a mersure of computer speed – being one computation a second.
- A teraflop is therefore 10^{12} (a trillion) computations a second – the speed reached by the fastest supercomputers in the mid-2000s

Conversion Factors

Length, Area & Volume

1 inch = 2.54 cm

1 metre = 39.4 inches

1 mile = 1.609 km

1 metre/sec = 3.60 km/hr = 2.24 mph

1 nautical mile = 1.15 miles

9.46×10^{15} metres = 1 light-year

3.086×10^{16} metres = 1 parsec

1 hectare = 10,000 sq. metres (ie 100 metres sq.) = 2.471 acres

1 acre = 4840 sq. yds (ie c70 yds sq.)

1 litre = 0.22 galls = 1.76 pints = 0.001 cubic metre

1 UK gallon = 1.20 US gall

1 cubic metre = 35.3 cubic feet

1 unit of alcohol = 10 millilitres (Therefore one-third of a bottle (250ml) of a 10% proof wine contains 2.5 units of alcohol.)

Oil

1 barrel = 159 litres = 35 UK galls = 42 US galls

1 tonne of oil = 7.48 barrels = 1.19 cubic metres

N.B. 1 barrel per day = 58 cubic metres pa = 48.8 tonnes pa
(ie typical density of oil = 0.87)

Gas

1000 cubic metres of gas = 1 cubic metre of oil equivalent

1 cubic metre contains approx. 9000 kcal

1 barrel of oil equivalent = 159 cu metres gas = 5900 cubic feet gas

Non-gas Liquids

1 tonne NGL = 1.3 cubic metres oil equivalent

Force

1 Newton = 100,000 dynes

Pressure

1 Pascal = 1 Newton/square metre

1 hecto-Pascal = 1 millibar

Energy

1 Joule = 10,000,000 ergs

1 Calorie = 4.186 joules

1 kcal = 3.92 BTU

1 Kilowatt-hour = 3.6 million joules (ie 1000 joules/sec for an hour)

1 Megajoule = 0.278 Kilowatt-hrs

1.6×10^{-19} joules = 1 electron-volt (the energy gained by an electron accelerated through an electrostatic potential difference of one volt)

Power

1 watt = 1 joule/second
1 horsepower = 746 watts.

Weight

1 gram = 0.0353 ounce (strictly avoirdupois ounce; 1 gram is 0.0322 troy ounce – a slightly heavier unit mainly used for measuring the weight of precious metals)
1 kg = 2.205 lb.
1 ton = 1.016 tonne
1 tonne = 1000kg
1 ml water weighs 1 g.
1 litre water weighs 1kg

Temperature

degrees kelvin = degrees celsius + 273
degrees fahrenheit = degrees celsius x 1.8 + 32

Old English

1 quart = 2 pints
1 pint = 4 gills = 20 fluid ounces
1 tablespoon = 18.5 ml
1 dessert spoon = 12.3ml
1 teaspoon = 6.2ml
1 breakfast cup = 284 ml
1 standard cup = 250ml
1 yard = 3 feet = 36 inches

Derived Units:

Contents:-

- Volume: the litre
- Force: the Newton
- Pressure: the Pascal
- Energy: the joule
- Power: the watt

One of the most common derived units is **Volume**. The basic SI unit is 1 *metre*³. But as this is fairly large, it is much more usual to use 1 **litre** which is 0.001 m³ or 1 millilitre which is 0.001 litres.

Another derived unit is **Force**. What does a force do? It causes a body to start to move and then, if there is no resistance, to go faster and faster – i.e. to accelerate. So the basic unit is the force that makes a mass of *1 kilogram* accelerate to a velocity of *1 metre/second* if the force is applied for *1 second*. (All the measurements in *italics* are SI Base Units.) Put more shortly, the basic unit of force is kilograms x metres/ seconds x seconds which shortens to kg.m/sec². As this is rather complicated, it is also known more simply as a **Newton**.

A Newton is quite a large force. After all, any force that can accelerate 1 kg to a speed of 1m/sec (3.6 km/hr) in only 1 second is quite powerful.

The Gravitational Force attracting two masses which are r metres apart is GMm/r², where G is 6.67x10⁻¹¹ Nm²/kg².

On the Earth, a mass of 1 kg is subject to a gravitational force of c 9.8 Newtons:- ie it weighs 9.8 Newtons. So if it falls for one second, it reaches a speed of 9.8 metres/sec or 35 km/hour. It is interesting to note that it does not travel 9.8 metres in that first second of falling, but starts at 0.0 m/sec and then only reaches the speed of 9.8 m/sec after one second. Its average velocity is therefore only half of 9.8 m/sec, i.e. 4.9 m/sec. This in turn means that if you jump off a 4.9 metre high wall you will hit the ground only one second later, and will be travelling at 9.8 m/sec (or 35 kph or 22 mph) when you do so:- Not a good idea!

Gravitational Acceleration varies slightly from place to place. It is 9.83 m/sec² at ground level at the North Pole, but (a) it decreases with altitude, and (b) it decreases towards the equator (where it is 9.78 m/sec²) because the Earth is slightly broader around the equator.

Because the Newton is such a large force, it is often convenient to use a much smaller unit of force, the **dyne**, which is the force which accelerates 1 gram by 1 cm/sec/sec. There are therefore 100,000 dynes in a Newton.

Pressure is the amount of force acting over an area, so its basic unit is force/m² ie Newtons/square metre. This unit is also known as a **Pascal**. Reduced to SI basic units, the dimensions are kg.m/sec² m² = kg/m.sec².

The mass of 1 m^3 of air at sea level is c1 kg. The gravitational force acting on it is therefore c10 Newtons, so that a metre's depth of air applies a pressure at sea level of around 10 Pascals. The total pressure of the column of air above seal level is around 10^5 Pascals, i.e. 10^3 hectopascals (or 10^3 millibars or 1 bar).

An increase in pressure of one hectopascal/millibar will lower sea level by c1cm. Tide tables assume a standard pressure of 1013 hectopascals, so an increase to 1040 hectopascals will lower sea level by c30 cm – which can be noticeable.

The atmosphere thins exponentially (at lower levels) with a half-height of about 5600 metres. There is therefore only 25% of the atmosphere above you (with a corresponding decrease in available oxygen) at 11200 metres (36400 feet):- the cruising height of many jets and a little higher than the summit of Everest.

Another way of looking at force is to think of it as the way in which **Energy** is transferred from one form to another. For instance a rocket motor uses chemical energy to force the rocket to gain kinetic energy. The basic unit of energy is the energy that is used when a basic unit of force pushes through a distance of 1 metre. The basic unit is therefore $(\text{kg.m/sec}^2) \times \text{m} = \text{kg.m}^2/\text{sec}^2$. This unit is known as a **Joule**.

Note that the dimensions of energy are mass x velocity². This is consistent with Einstein's suggestion that mass m can be converted into energy E and that when this happens then $E=mc^2$, where c = the speed of light. It can also be calculated that a mass of m gram travelling at v cm/sec has kinetic energy of $0.5mv^2$ joules.

There are of course several different forms of energy, with lots of different names.

Sound and *heat* are both forms of *kinetic* energy of atoms and molecules.

Potential energy derives from the position of an object:- ie a weight that is lifted away from the centre of the Earth has gravitational potential energy, whilst a stretched or compressed spring has elastic potential energy.

Kinetic and potential energy are both in turn different forms of *mechanical* energy.

And yet other forms of energy include *chemical*, *electrical*, *nuclear* and *radiant* (inc. light and radio waves).

Like the Newton, the Joule is quite a large unit. It is therefore sometimes useful to use the erg which is the work done when 1 dyne operates through 1 cm. As there are 100,000 dynes in a Newton, and 100 cms in a metre, there are 10 million ergs in a joule.

Heat energy is more often measured in calories. 1 calorie is the heat required to raise the temperature of 1 gram of water by 1 degree Celsius. 1 calorie is equivalent to 4.186 joules.

(A mass of 1 kg falling through 1 metre on Earth therefore releases 9.8 joules of potential energy – ie just over 2 calories of energy. This is enough energy to heat 1 gram of water by 2 degrees C, or itself (1 kg) by 0.002 degrees C.)

Power is the rate at which energy transferred from one form to another. **1 watt** is the same as 1 joule/second.

A 100 watt light bulb therefore generates 100 joules every second or 24 calories every second. In other words it could raise the temperature of 1 gram of water by 24 degrees C every second – and boil it in about 4 seconds. An RB211 aero engine generates 30 megawatts, ie 30 million joules/second (the sort of power needed by a town of about 60,000 people).

Sound & Light

Imagine standing still as waves go past you. If 10 wave crests go past you every minute, and the distance between the crests is 2 metres, then the waves must be travelling at 20 metres a minute. In other words the speed of a wave is its length x its frequency.

The speed of **sound** depends upon the medium through which it is travelling and on the temperature. In air, at room temperature, the speed of sound is 300m/sec. So a gap of 3 or 4 seconds between lightning and thunder means that it is about 1km away.

The speed of sound is much faster (1500m/sec) in water and faster still (6000m/sec) in steel:- which is why you can hear a train coming a long way away if you put your ear to the rail.

The speed of **light** (indeed, the speed of **all electromagnetic radiation**) *in a vacuum* is 3×10^8 m/sec. (It goes slower if not in a vacuum, which is why light

is bent when entering water or glass at an angle – This is called refraction.)
 And as speed = frequency x wavelength, the latter increases as the former falls.
 The result is the ...

Electromagnetic Spectrum

	<u>Frequency</u> Hertz (ie cycles/sec)	<u>Wavelength</u> metres
Gamma rays	3×10^{19}	10^{-11}
X rays	3×10^{17}	10^{-9}
Ultra-violet	3×10^{15}	10^{-7}
Violet light	7×10^{14}	4×10^{-7}
Red light	4×10^{14}	7×10^{-7}
Infra-red	3×10^{13}	10^{-5}
Microwaves	3×10^{10}	10^{-2}
UHF radio	$3 \times 10^8 - 3 \times 10^9$	$10^{-1} - 1$
Professional VHF radio (ie aircraft, police, taxis)	$1.08 - 1.36 \times 10^8$	$2.2 - 2.7$
Broadcast VHF radio (frequency modulated)	$0.88 - 1.08 \times 10^8$	$2.7 - 3.4$
TV	$5.5 - 8.7 \times 10^7$	$3.5 - 5.5$
Short wave radio	$0.6 - 3 \times 10^7$	$1 - 5 \times 10^1$
Medium wave radio (amplitude modulated)	$0.5 - 1.7 \times 10^6$	$1.8 - 6 \times 10^2$
Long wave radio	$1.5 - 3 \times 10^5$	$1 - 2 \times 10^3$
Electro-magnetic waves (e.g. near power lines)	$5 - 6 \times 10^1$	$5 - 6 \times 10^6$

Geology, the Earth etc.

The Earth's radius is 6357km at the North Pole. It is slightly higher (because of the Earth's spin) at 6378km at the equator.

The mass of the Earth is c. 6×10^{24} kg

The density of air is 1.22 kg/m^3 at ground level and 0.47 kg/m^3 at 9000m.

Igneous rocks are formed from molten rock (magma) that becomes solid when it cools.

- Lavas etc. are extrusive and cool very quickly, forming very small crystals.

- Others, (e.g. granite) are intrusive, i.e. formed deep underground. Slow cooling forms much bigger crystals. Such rocks are exposed as a result of erosion.

Sedimentary rocks are laid down in layers.

- Sand on a beach and mud on a river bed creates e.g. sandstones.
- Marine organisms create limestones, inc. chalk.

Metamorphic rocks are existing rocks that have changed form under high pressure and/or temperature, e.g. after deep burial in the Earth.

- These rocks (e.g. schist, slate and marble) are also crystalline, but the crystals form in the solid state.
- Slate was originally fine mud.
- Marble is formed from limestone. It does not have a banded structure and so can break in any direction, making it ideal for sculpture.

All three types of rock can turn into the other two types through burial, extrusion and erosion/deposition.

Atoms, radiation etc.

There are 6×10^{23} atoms in 1 mole of a substance (i.e. 1 gram of Hydrogen, 12 grams of Carbon).

The rest mass of a proton is 1.67×10^{-27} kg.

The charge on an electron is 1.6×10^{-19} coulombs.

The heaviest naturally occurring element is uranium which has 92 protons.

Heavier elements up to fermium (100) have been created by firing protons at uranium nuclei. Firing heavier atoms (such as C, N or O) subsequently allowed the creation of elements up to an as yet un-named 112, with lives of the order of 100-200 micro-seconds. It is predicted that No. 114, when it is made, might be more stable.

Atomic disintegrations create three types of radioactivity:- Alpha particles are the nuclei of helium atoms, Beta particles are electrons, and Gamma rays are electromagnetic radiation with very short wavelength.

1 Becquerel = 1 atomic disintegration/sec.

Manufactured substances must be treated as radioactive, and carefully stored etc., if 1 kilogram of the substance produces more than 380 disintegrations a second – i.e. their radioactivity exceeds 380 becquerel/kilogram (Bq/kg).

The commonest naturally occurring radioactive element is potassium. There is enough radioactive potassium in the following substances to produce the following radioactivity:

Humans: 140 Bq/kg
Coal: 250 Bq/kg
Tea: 830 Bq/kg
Coffee: 1640 Bq/kg.



Note, therefore, that tea and coffee would need to be stored in special containers, carrying the above sign, if they were not naturally occurring substances!

Subatomic Particles

Everything in the Universe (ie “matter”) consists of *leptons* and *quarks* bound together by messenger particles called *bosons*.

There are 6 **leptons**:

	<u>charge (<i>e</i>)</u>
Electron	-1
Muon	-1
Tau	-1
Electron-neutrino	0
Muon-neutrino	0
Tau-neutrino	0

And there are 6 **quarks**:-

	<u>charge (<i>e</i>)</u>
Down	-1/3
Strange*	-1/3
Bottom*	-1/3
Up	+2/3
Charm*	+2/3
Top*	+2/3.

*These 4 quarks are heavier and more unstable.

There are four types of **force** or **interaction**: gravity, electromagnetism and the strong and weak nuclear forces, carried by a number of **bosons**. The existence of the four gauge bosons (photons, W and Z bosons, and gluons) has been confirmed. The existence of the Higgs boson and the graviton are not yet confirmed.

Photons are the force carriers of the electromagnetic field. W and Z bosons are the force carriers which mediate the weak nuclear force. Gluons are the fundamental force carriers underlying the strong nuclear force.

Non-fundamental particles such as protons and neutrons consist of a number of quarks in various combinations. For instance, a proton is made of 2 Up quarks and 1 Down.

Every fundamental particle has a corresponding **anti-particle** with the same mass but opposite charge. For instance, the anti-particle of the down quark has a charge of $+1/3 e$.

Biology

This is a list of the living things whose ancestors branched away from the line which became man (homo sapiens) in the order in which they are believed to have branched off. **Words in bold indicate major classifications.**

Eubacteria inc. cyanobacteria, bacillus, E coli

Archeans – leaving **Eukaryotes:-**

Various eukaryotes, inc seaweeds, slime moulds, some amoeba

Plants, inc. red & green algae

Some other Amoeba

Fungi (some of which associate with algae or cyanobacteria to form lichens)

DRIPs

Choanoflagellates – leaving **Animals:-**

Sponges

Placozoans

Ctenophores

Corals, sea anemones, jellyfish

Acoelomorph flatworms– leaving animals with body cavities and anuses
Worms, insects (beetles, flies, crickets – 6 legs), centipedes, spiders (8 legs), crustaceans (crabs, lobsters, woodlice), molluscs (slugs, snails, mussels, octopus, cuttlefish, squid), etc.

Starfish, sea urchins etc.

Sea squirts

Lancelets

Lampreys and hagfish – jawless fish

Sharks, skates, rays etc: leaving **bony animals**:

Ray-finned fish

Coelacanths

Lungfish: leaving **tetrapods**:

Amphibians: frogs, toads, salamanders, newts

Birds (warm blooded) **and reptiles** inc. dinosaurs, crocodiles, lizards, snakes, turtles

Duckbilled platypus: leaving (warm blooded) **mammals**:

Marsupials: leaving **placental mammals**:

Elephants, dugongs, manatees, armadillos

Armadillos, sloths and anteaters

Dogs, cats, bears, seals, horses, deer, hippos and whales

Rabbits and rodents

Tree shrews and colugos

Lemurs, bushbabies, lorises and pottos

Tarsiers

New World monkeys

Old World monkeys - baboons etc.

Gibbons

Orang Utans

Gorillas

Chimpanzees

Other information

All human cells (except eggs, sperm and red blood cells) contain a nucleus and 2 sets of **genome**. Each genome contains 23 chromosomes consisting of an intertwined pair (i.e. a double helix) of very long DNA molecules, off which are several thousand side rungs called **genes**. Each gene itself consists of many

thousands of **codons**, each which in turn contains three (of four available) **bases** – adenine, cytosines, guanine and thymine (usually abbreviated to A, C, G & T).

The genes are translated into **proteins** by RNA. Proteins are relatively large organic compounds made up of **amino acids**. They are essential parts of all living organisms and participate in every process within cells. Many proteins are enzymes that catalyse biochemical reactions in the body. Other proteins have structural or mechanical functions, such as the proteins which form a system of scaffolding that maintains cell shape. Protein is also a necessary component in our diet, since animals cannot synthesise all the amino acids they need and must obtain some essential ones from food. Through the process of digestion, animals break down ingested protein into free amino acids that can be used for protein synthesis.

Viruses are genetic entities that are metabolically inert except when they infect a host cell, when the virus inserts its own genetic material and literally takes over the host's functions.

The lifespan of mammals is roughly in proportion to the animal's mass to the power of 0.25. And metabolic rate (e.g. heart rate) is roughly in proportion to mass to the power of -0.25 . Total energy consumption is roughly in proportion to mass to the power of 0.75.

A 10,000kg elephant will therefore live 10 times as long, and have a heart rate $1/10^{\text{th}}$ of, a 1kg hen.

A 100kg man burns energy at the rate of 100 watts – or 24 cal/sec – or 2m cal/day i.e. 2000 kcal/day.

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