A Dummy's Guide to
Science

Do you ever feel confused by expert colleagues, and too ashamed to ask what they mean by radioactivity, 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 helpful information 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. (SI = Systeme International d'Unites)

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

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

quecto	?	10^{-30}	
ronto	?	10^{-27}	
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}	
ronna	?	10^{27}	
quetta	?	10^{30}	

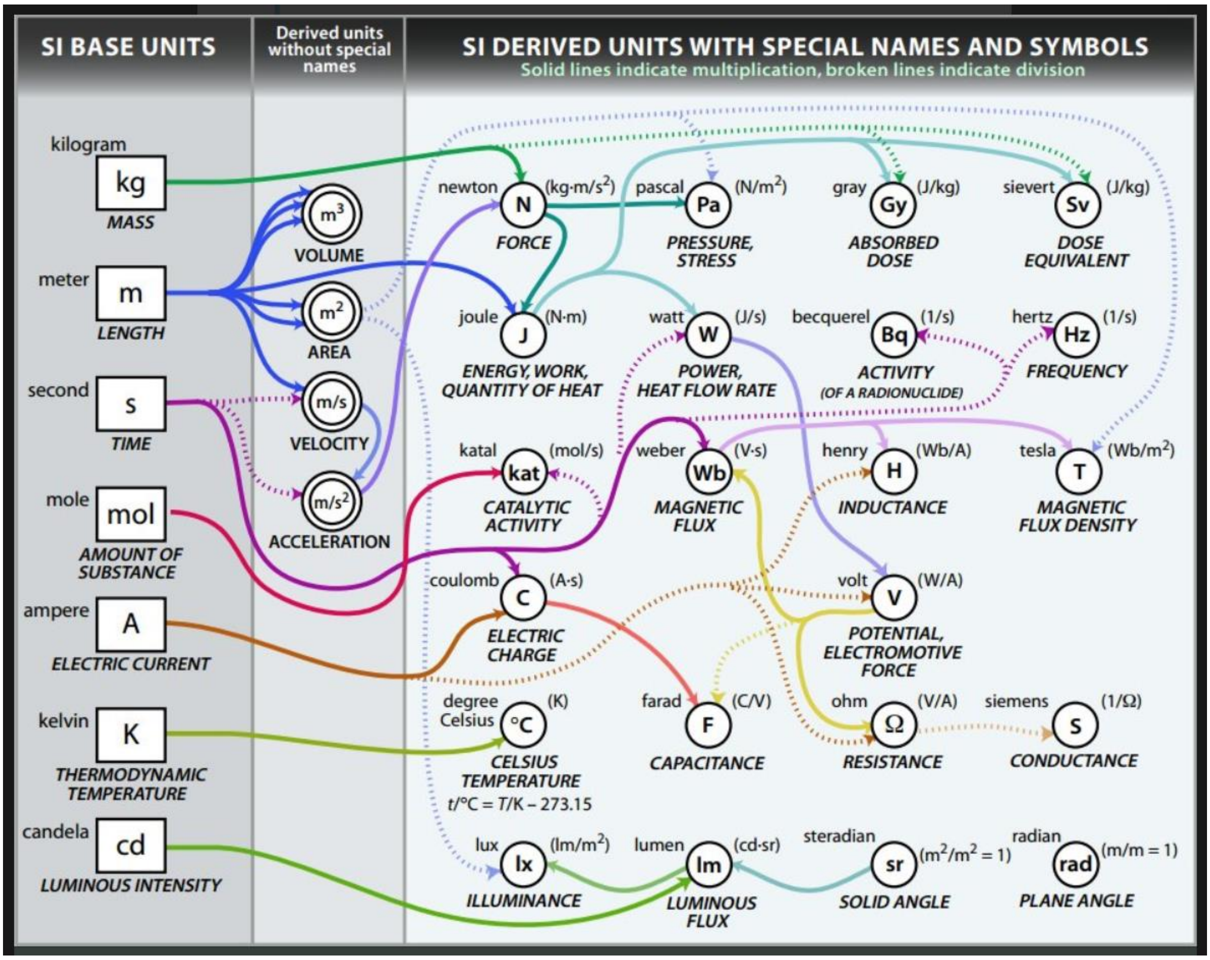
The mass of the Earth is around 6 ronnagrams.
The mass of an electron is around 1 rontogram.

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

- 1 bit is one unit of storage in a computer (i.e. a "0" or a "1").
- A byte is 8 bits (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 measure 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

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


SI BASE UNITS
Derived units without special names
SI DERIVED UNITS WITH SPECIAL NAMES AND SYMBOLS
Solid lines indicate multiplication, broken lines indicate division
kilogram kg MASS
meter m LENGTH
second s TIME
mole mol AMOUNT OF SUBSTANCE
ampere A ELECTRIC CURRENT
kelvin K THERMODYNAMIC TEMPERATURE
candela cd LUMINOUS INTENSITY
m³ VOLUME
m² AREA
m/s VELOCITY
m/s² ACCELERATION
newton N (kg·m/s²) FORCE
pascal Pa (N/m²) PRESSURE, STRESS
gray Gy (J/kg) ABSORBED DOSE
sievert Sv (J/kg) DOSE EQUIVALENT
joule J (N·m) ENERGY, WORK, QUANTITY OF HEAT
watt W (J/s) POWER, HEAT FLOW RATE
becquerel Bq (1/s) ACTIVITY (OF A RADIONUCLIDE)
hertz Hz (1/s) FREQUENCY
katal kat (mol/s) CATALYTIC ACTIVITY
weber Wb (V·s) MAGNETIC FLUX
henry H (Wb/A) INDUCTANCE
tesla T (Wb/m²) MAGNETIC FLUX DENSITY
coulomb C (A·s) ELECTRIC CHARGE
volt V (W/A) POTENTIAL, ELECTROMOTIVE FORCE
degree Celsius °C (K) CELSIUS TEMPERATURE
t/°C = T/K – 273.15
farad F (C/V) CAPACITANCE
ohm Ω (V/A) RESISTANCE
siemens S (1/Ω) CONDUCTANCE
lux lx (lm/m²) ILLUMINANCE
lumen lm (cd·sr) LUMINOUS FLUX
steradian sr (m²/m² = 1) SOLID ANGLE
radian rad (m/m = 1) PLANE ANGLE

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 (i.e. 100 metres sq.) = 2.471 acres
1 acre = 4840 sq. yds (i.e. 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
(i.e. 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

Weight, Mass & Energy

Einstein showed that mass and energy are fundamentally the same. $E=mc^2$ where c is the speed of light, 3×10^8m/sec. So 1 kg = 9×10^{16} Kgm^2/sec^2 or 9×10^{16} joules

1 Joule = 10,000,000 ergs
1 Calorie = 4.186 joules
1 kcal = 3.92 BTU
1 Kilowatt-hour = 3.6 million joules (i.e. 1000 joules/sec for an hour)
1 Megajoule = 0.278 Kilowatt-hrs

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

The mass of a fundamental particles such as a quark or a boson is typically converted into their mass-energy measured in giga-electron-volts (GeV or 10^9eV).
1.6×10^{-19} joules = 1 electron-volt (the energy gained by an electron accelerated through an electrostatic potential difference of one volt)

1 GeV = $10^9 \times 1.6\times10^{-19}$ joules = 1.6×10^{-10} joules = 1.78×10^{-27} kg (after dividing by c^2.)

Power

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

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 m^3 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/sec^2. 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/r^2, where G is 6.67x10^{-11} Nm^2/kg^2.

On the Earth, a mass of 1 kg is subject to a gravitational force of c 9.8 Newtons:- i.e. 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/sec^2 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/sec^2) 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/m^2 i.e. Newtons/square metre. This unit is also known as a Pascal. Reduced to SI basic units, the dimensions are kg.m/sec^2 m^2 = kg/m.sec^2.

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 (kg.m/sec^2)x m = kg.m^2/sec^2. This unit is known as a Joule.

<u>Note</u> that the dimensions of energy are mass x $velocity^2$. 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:- i.e. 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.
- 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 – i.e. 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, i.e. 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 <u>speed</u> of a wave is its <u>length</u> x its <u>frequency</u>.

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 x 10^8m/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

	Frequency Hertz (i.e. cycles/sec)	Wavelength metres
Gamma rays	$3x10^{19}$	10^{-11}
X rays	$3x10^{17}$	10^{-9}
Ultra-violet	$3x10^{15}$	10^{-7}
Violet light	$7x10^{14}$	$4x10^{-7}$
Red light	$4x10^{14}$	$7x10^{-7}$
Infra-red	$3x10^{13}$	10^{-5}
Microwaves	$3x10^{10}$	10^{-2}
UHF radio	$3x10^8$ – $3x10^9$	10^{-1} – 1
Professional VHF radio (i.e. aircraft, police, taxis)	1.08 – $1.36x10^8$	2.2 – 2.7
Broadcast VHF radio (frequency modulated)	0.88 – $1.08x10^8$	2.7 – 3.4
TV	5.5 – $8.7x10^7$	3.5 – 5.5
Short wave radio	0.6-$3x10^7$	1 – $5x10^1$
Medium wave radio (amplitude modulated)	0.5 – $1.7x10^6$	1.8 – $6x10^2$
Long wave radio	1.5 – $3x10^5$	1 – $2x10^3$
Electro-magnetic waves (e.g. near power lines)	5 – 6 $x10^1$	5 – 6 x 10^6

As noted above, light goes more slowly if not in a vacuum. The extreme case is when it travels at very low temperatures through a weird substance called a Bose-Einstein condensate when its speed has been reduced to 17 metres/sec – the speed of a sports cyclist!

Geology, the Earth etc.

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

The mass of the Earth is c. $6x10^{24}$ 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 $6x10^{23}$ atoms in 1 mole of a substance (i.e. 1 gram of Hydrogen, 12 grams of Carbon).
The rest mass of a proton is $1.67x10^{-27}$ kg.
The charge on an electron is $1.6x10^{-19}$ coulombs.

The mass of subatomic particles is more usually quoted in Giga Electron Volts (GeV) or atomic mass units. A proton weighs 1 amu or 0.93 GeV. 1 GeV is 1.783×10^{-27} kg.

The heaviest naturally occurring element is uranium which has 92 protons. Heavier elements have been created in laboratories, up to the as yet un-named element 118.

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

As mass and energy are two sides of the same coin (remember $E=mc^2$) scientists say that ordinary matter - gas, stars, planets and galaxies - makes up just 5% of the Universe. Dark energy makes up about 68%, and dark matter - which does not reflect or emit detectable light - accounts for 27%. But if we discount the energy part of the universe, and just look at mass, then the Universe is 85% dark matter and 15% normal or **baryoni**c matter.

Dark matter may consist of WIMPs (weakly interacting massive particles) and/or Axions.

All ordinary matter consists of **fermions** bound together by messenger particles called **bosons**.

There are 12 **fermions**: **6 leptons** (electron, muon, tau, electron neutrino, muon neutrino and tau neutrino) and 6 **quarks** (up, charm, top, down, strange & bottom).

There are believed to be 6 elementary **bosons** as well as a number of composite ones. The existence of the Higgs boson and the four gauge bosons (photons, gluons, and the W and Z bosons) has been confirmed. The existence of the graviton is not yet confirmed.

The **Higgs boson** gives particles their mass. The other bosons provide four types of force or interaction:

Gravity – the attractive force - carried by **gravitons**
Electromagnetism – the interaction between bodies with electric charge - carried by **photons**
The Strong Nuclear Force – keeps protons and neutrons together in an atom's nucleus - carried by **gluons**
The Weak Nuclear Force – governs things like radioactive decay - carried by **W and Z bosons**

The top quark is the heaviest of these 18 fundamental particles. Its mass energy is 172 GeV (gigaelectronvolts). (See above for conversion factors.)

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.

Biology

It is not yet known how chemicals managed to develop life-like properties, but biology then began with two enormously diverse groups of single celled microorganisms (microbes) known as **Bacteria** and **Archaea**.

A merger between these two ancient cell types, billions of years later, is thought to have created **Eukaryotes**, which are organisms whose cells contain complex structures enclosed within membranes. The defining membrane-bound structure is the nucleus, or nuclear envelope, within which the genetic material is carried. All species of large complex organisms are eukaryotes, including animals, plants and fungi.

Richard Dawkins & Yan Wong's *The Ancestor's Tale* summarises the order in which our living relatives subsequently branched off the evolutionary line that became homo sapiens. The principal departures were as follows:

> Various eukaryotes, inc. seaweeds, slime moulds, some amoeba, were next leave, and then ..
> **Plants,** inc. red & green algae, and then …
> **Fungi** (some of which associate with algae or cyanobacteria to form lichens)
> … which left **Animals**.
>
> Sponges
> 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.
> Lampreys and hagfish – jawless fish
> Sharks, skates, rays etc:
>
> leaving **bony animals**:
>
> Coelacanths
> Lungfish, who left …
>
> **Tetrapods,** which are vertebrate animals having four limbs.
>
> > Even snakes and other limbless reptiles and amphibians are tetrapods by descent.
>
> Subsequent departures were
>
> **Amphibians**: frogs, toads, salamanders, newts
> **Birds** (warm blooded) and reptiles inc. dinosaurs, crocodiles, lizards, snakes, turtles - leaving (warm blooded) **mammal**s:

Marsupials: leaving placental mammals:

Elephants, dugongs, manatees, aardvarks
Dogs, cats, bears, seals, horses, deer, hippos and whales
Rabbits and rodents
Monkeys
Orang Utans
Gorillas
Chimpanzees – our closest relatives.

Note that we are **not** descended from monkeys, no more than we are descended from our human cousins. But we do have common ancestors.

There are thought to be between 10 and 100 **million** separate species of organisms on earth, of which only around 1.5 million are known to scientists.

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).

Cells divide to enable us to grow, and they carry on dividing after we have reached adulthood, partly so as to repair damage. Random DNA copying mistakes during cell division can cause **cancer**. Basal skin cells divide 10 trillion times in a lifetime, and are therefore relatively likely to cause skin cancer, at least in comparison to, say, pelvic bone cells which only divide around 1 million times in a lifetime.

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.

The reproduction of DNA causes the vast majority of the attributes of living things to be inherited by later generations. But molecules outside cells can switch genes on and off, and these new attributes can themselves be inherited, on top of the organism's genetic code. These heritable traits are known as **epigenetics**.

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 1/10th of, a 1kg hen.

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

Here is a nice image which neatly shows the tiny size of viruses and other very small particles.

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