Science and Statistics
A Primer for Policy Advisers

Policy advisers often have to incorporate advice from their scientist and statistician colleagues when preparing papers for ministers and other decision makers. Such colleagues will do their best to explain basic scientific facts, statistical traps and associated jargon. But non-scientists can find it very helpful if they first do a little background reading.

The following notes re based on those I made during my career in the Business Department and Better Regulation Executive. (Further contributions would be very welcome.) They will not make you an expert in the various subject areas - nor should you try to become one - but they will help you understand what you are being told, and so help you, in turn, to prepare sensible, easy to understand, policy advice.

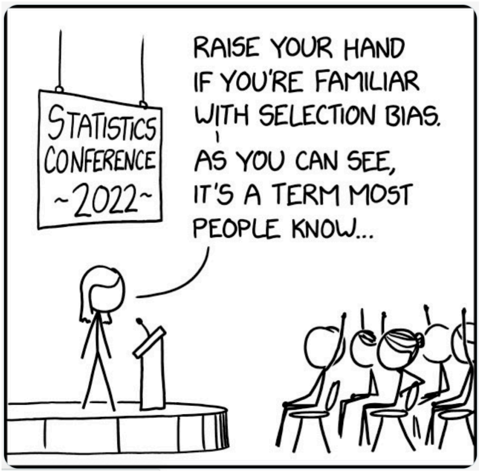
Contents

1. Statistics

Sound policies - and sound science - rely on sound data, but statistics can be very misleading. Here are summaries of some of the problems.

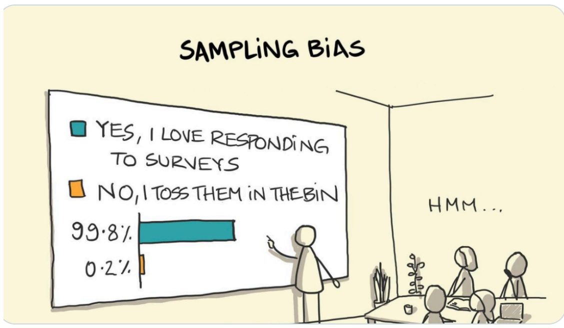
Publication Bias:- Studies that show interesting results are more likely to get published than those that don't. So if two studies look at red meat and cancer, for instance, and only one shows a link, that one is more likely to be published. This bias happens at nearly every stage of the long process from the initial research to publication in a scientific journal and ultimately to news stories.

Selection Bias:- The person or organisation providing the data may, deliberately or otherwise, have selected data which supports their interests or their point of view.



- Managers at all levels may offer data which makes their performance look good, whilst failing to draw attention to less flattering information.
  - (This is a particular problem in regulatory policy making where the information advantage of the regulated entity is called *information asymmetry*.)

Sampling Bias:- Those who do not respond to surveys may have very different views to those who do. Imagine a 30 to 10 split "in favour" in responses to a questionnaire. Does this mean that "75% believe that ..." ? Not if the response rate was 40% and almost all the remaining 60% thought not.



Aggregated statistics can look very different to the underlying figures.

- Vehicle accident statistics, for instance, generally include young and accident-prone drivers, as well as injuries to pedestrians and cyclists. A middle-aged car driver undertaking a long journey in good weather may well be just as safe as if they were flying, which is a very safe form of transport.
- Apparently worrying death rates can look much less scary when you discover that they average the health outcomes of those who were previously very ill with those who were previously healthy. A report of deaths caused by, for example, air pollution might include a high proportion of those whose death was already imminent, rather than deaths from amongst an otherwise healthy population.
- Small sample sizes can produce very misleading results. Try to identify or organise meta research which aggregates the results of numerous smaller samples.

- Isolated statistics can give a misleading impression. For instance, the radioactivity of a beach near a nuclear plant may be higher than many others, but is it also lower than other beaches which are nowhere near such a plant?

Those responding to questionnaires may not tell the truth, inadvertently or deliberately

- Few of us can accurately recall what we have eaten, and may deliberately or otherwise under-report alcohol consumption, for instance - or cake consumption in my case.
- Students and patients may not be the best judge of the quality of their teachers or doctors respectively. Professors who perform in an entertaining way, and doctors with great bedside manners, may be far from the best in their profession. Remember Harold Shipman ...!
    - Professor Ricard Tol tweeted that "I put more stock in student evaluations years after the fact. Every so often a former student tells me (s)he hated me at the time, but now realizes that I really taught them something ..."
    - Students are unlikely to say that they have undertaken a useless university course, where they learned little, for they will need that course/university to have a good reputation when they come to apply for jobs.
    - Teenage kids will often give absurd answers just to have a laugh.

Different organisations will record data in different ways. The classic example is in France where, if an elderly person is found dead without evidence of health problems, it is acceptable to attribute the death to 'old age', thus reducing the apparent incidence of heart attacks. But crime statistics can be similarly unreliable, as are many others.

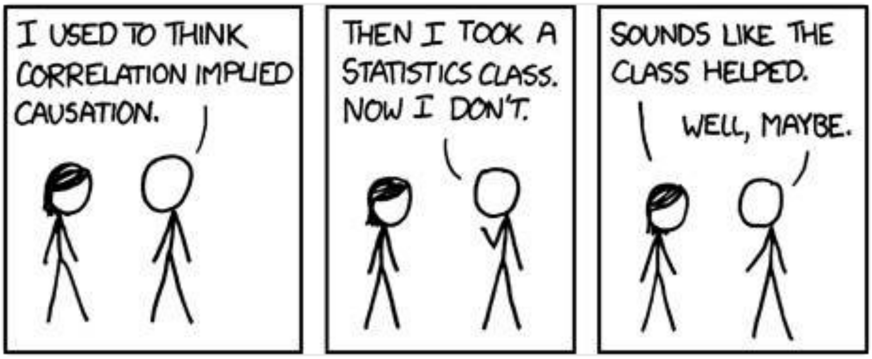
The fact that there have been no incidents does not mean that something is safe.

- Catastrophes are, by definition, low probability, high consequence events. One terrible example was the Grenfell Tower fire where the government had come to believe that its regulatory approach was sound because the number of deaths from fires has been falling.
- One reason why fewer children are now killed on our roads is not because they are inherently safer than decades ago, but rather because they are so dangerous that many children are not allowed near them.

Death, illness and injury rates can look very different when presented as a number (e.g. number of children killed in an incident) rather than as a proportion of the exposed population per annum.

Survival rates can also be very misleading. Screening for cancer, for instance, often appears to generate a high survival rate (over 5 years, say) compared with the survival rate of those whose cancers are detected when symptoms become obvious. But this can be because the cancers are diagnosed earlier, so it appears that patients live longer even if treatment is ineffective. Or it can be because the tests also identify slow growing and essentially harmless cancers.

Above all, ***correlation does not prove causation!***



So what is to be done? If possible, you should design your own questionnaires and data-gathering exercises with the help of professional statisticians. To the extent that this is not possible, you must treat all data with a heavy dose of cynicism, bearing in mind all the issues listed above.

But do not be tempted, when faced with a hostile press or a one-sided lobby, to assemble your own dodgy statistics – or dodgy science – to fight them off. The inevitable result would be that those with whom you are trying to communicate would then see you as prejudiced and/or adversarial, and you might also then fail to pay insufficient attention to perfectly reasonable arguments from 'the other side'. Instead, follow this link to read and apply some excellent advice about **how to communicate statistics.**

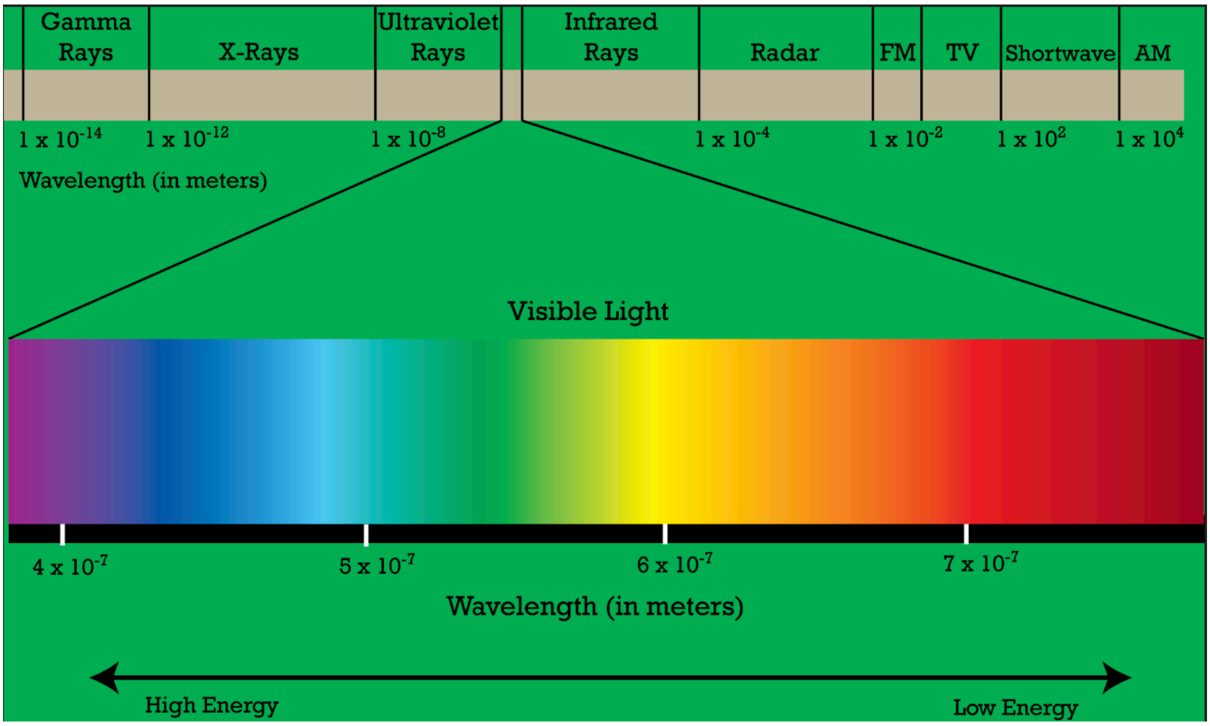
Further Reading

There are lots of good books about the use and abuse of statistics, written for non-experts. All policy makers should read David Spiegelhalter's *The Art of Statistics: Learning from Data* - a wonderfully accessible text for non-statisticians. As well as almost everything by Professor Spiegelhalter, I recommend almost everything by Tim Harford, including *How to Make the World Add Up.*

2. Radiation

'Radiation' sounds scary but most of it is entirely harmless, and indeed essential for life as we know it. Light is radiation, for instance, as is the wifi in our home and offices.

There is a **radiation spectrum**, ranging from very energetic and dangerous radiation (to the left in the following chart) through to very low energy and very safe radiation (to the right). Wifi and microwaves are around 100mm (1x-10^{-1} metres) by the way, firmly in the safe end of the spectrum.



It is useful to separate out three principal types of radiation within this spectrum. Let's do so in order of decreasing energy - starting from the left in the above chart,

1. Ionising Radiation (aka Radioactivity) This - the most energetic radiation - is very dangerous because it can ionise material in the body. Most ionisations are harmless, but there is a small chance that ionisation of DNA can cause cancer. The main components of this part of the spectrum are:

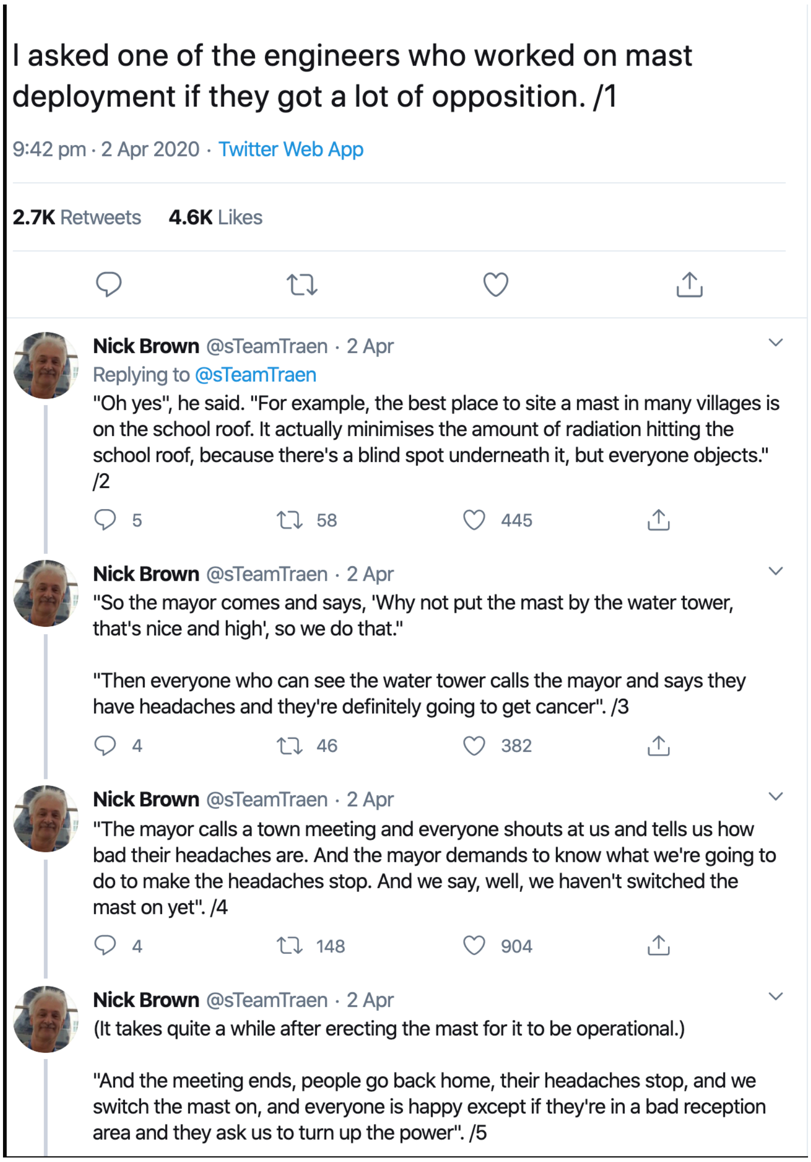
- Bits of atoms, emitted when radioactive material breaks up:- Alpha particles, Beta particles (electrons) and Neutrons.
- Gamma rays

There is more information about radioactivity in **Part 3** below

2. X-rays and Ultra-violet radiation comes next. These two forms of radiation are less dangerous but can still cause cancer - see **Part 4** below.

3. Visible light, infrared radiation (which we experience as heat) **and radio waves** make up the low energy end of the radiation spectrum. It is therefore highly unlikely that it could be doing us any damage.

There nevertheless remain frequent stories about the health risks associated with mobile phone signals. This tweet puts the problem in perspective:-



I asked one of the engineers who worked on mast deployment if they got a lot of opposition. /1

9:42 pm · 2 Apr 2020 · Twitter Web App

2.7K Retweets **4.6K** Likes

Nick Brown @sTeamTraen · 2 Apr
Replying to @sTeamTraen
"Oh yes", he said. "For example, the best place to site a mast in many villages is on the school roof. It actually minimises the amount of radiation hitting the school roof, because there's a blind spot underneath it, but everyone objects." /2

5 58 445

Nick Brown @sTeamTraen · 2 Apr
"So the mayor comes and says, 'Why not put the mast by the water tower, that's nice and high', so we do that."

"Then everyone who can see the water tower calls the mayor and says they have headaches and they're definitely going to get cancer". /3

4 46 382

Nick Brown @sTeamTraen · 2 Apr
"The mayor calls a town meeting and everyone shouts at us and tells us how bad their headaches are. And the mayor demands to know what we're going to do to make the headaches stop. And we say, well, we haven't switched the mast on yet". /4

4 148 904

Nick Brown @sTeamTraen · 2 Apr
(It takes quite a while after erecting the mast for it to be operational.)

"And the meeting ends, people go back home, their headaches stop, and we switch the mast on, and everyone is happy except if they're in a bad reception area and they ask us to turn up the power". /5

3. Radioactivity

Although radioactivity can be damaging, it is important to bear in mind that our natural environment is radioactive - typically amounting to 2.7 mSv a year. (See further below for what this means.)

So - if you get caught up in a radioactivity scare (maybe caused by a radioactive spillage) make sure that your scientific advisers tell you what **equivalent dose** (measured in **millisieverts**) might be received by those exposed to the radiation. They might well need to make a number of assumptions in calculating the dose(s), and these should be made explicit. But once you have a possible figure, you can compare it with the average dose of 2.7mSv that we each receive each year and decide how to react.

It follows that a further dose of a few mSv is not worrying. Indeed, a single dose of as much as 1,000 mSv is needed to cause temporary radiation sickness such as nausea and vomiting. By way of comparison, the equivalent dose exceeded 12mSv per hour in only the tiny, most polluted area around the failed Chernobyl reactor.

Let's take a step back.

The word radioactivity is scary in itself, but it doesn't help that our exposure to it can be measured in several different ways.

- The number of particles emitted by radioactive material depends upon the material's *half-life*, i.e. the time that it takes for one half of each unit of material to transform into another material.
- If we are handling radioactive material, we are usually more interested in the number of emissions that it creates every second. Even tiny amounts of radioactive substance generate huge numbers of emissions which are measured in *becquerels*. The shorter the half-life, and the heavier the material, the greater the number of becquerels. But these large numbers do not straightforwardly reflect the risk to humans.
- We are more interested in the amount of energy that is absorbed by the body when it is hit by radioactivity. This is measured in *grays*. For instance, a heavy alpha particle delivers much more energy (that is many more grays) than a lighter beta particle.
- We are even more interested in the damage that is done by the radioactivity. Here again, heavier particles, such as a alpha particles, do the most damage because they leave all their energy in one place. Damage is measured in *sieverts* but as most of us are subject to very little radioactivity in our normal lives, our personal doses are usually measured in one thousandths of a sievert or *millisieverts* (mSv).

An average person in the UK receives a dose of around 2.7mSv each year - a bit more in some areas, a bit less in others. This is around 200mSv, over a lifetime.

- 1.4 of this 2.7 comes from the naturally occurring gas Radon.
- Another 0.9 comes from other natural sources, including 0.3-0.4 from cosmic rays, and
- 0.4 comes from medical X rays etc. - a spinal X-ray delivers roughly 1mSv of radiation; and a CT scan of the abdomen and pelvis delivers an effective dose of 15mSv.
- Only 0.03mSv comes from industry, including radioactive discharges from power stations etc and fallout from e.g. Chernobyl.

The legal limit for exposure for someone working with radiation in industry is 20 mSv/year.

What are the natural sources of radioactivity?

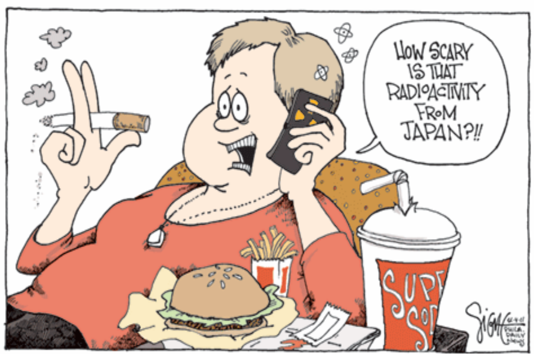
The biggest source is Radon gas, but almost all organic material contains radioactive Potassium 40. Indeed, there is enough radioactive Potassium in the following substances to produce the following radioactivity:

Humans:	140 Bq/kg
Coal:	250 Bq/kg
Tea:	830 Bq/kg
Coffee:	1,640 Bq/kg.

The law requires manufactured substances to be treated as radioactive, and handled carefully, if one kilogram of the substance produces more than 380 disintegrations a second – i.e. their radioactivity exceeds 380 Becquerel/kilogram (Bq/kg). (1 Becquerel = 1 atomic disintegration/sec.) Tea and coffee would therefore need to be stored in special containers, carrying the above sign, if they were not naturally occurring substances.

Even the Carbon Dioxide in the air that we breathe is radioactive. This is because cosmic rays entering the atmosphere create CO_2 containing *Carbon 14*, a radioactive form of carbon. This slowly turns into normal non-radioactive carbon But this happens so slowly that every gram of natural carbon (e.g. in our bodies, in the atmosphere as CO_2, or in plants) typically emits 15 radioactive particles every minute. This gradual reduction in radioactivity provides a way of establishing the age of very old organic material:- "carbon dating".

4. Cancer



What are the chances of getting cancer from radioactivity, X-Rays and Ultraviolet light?

The risk from radioactivity and X-Rays is thought to be about .005% per millisievert over a lifetime.

The average person in the UK receives a dose of 200mSv over their lifetime. The chances of this causing cancer are therefore 0.005% of 200 which is 1%. In other words, 1% of us will die from cancers caused by radioactivity. In contrast, 99% of us die from cancers caused by random DNA changes or by other factors, including smoking.

But some of us are subject to higher doses, and so suffer from elevated risk:-

- Radon gas escaping from the ground in Cornwall means that the average Cornish person receives c.8 mSv a year.
- Residents of Ramsar in Iran receive around 240 mSv a year for similar reasons.
- Some medical procedures (such as CT scans) can give doses of over 10 mSv - equivalent around three or more years worth of normal exposure..
- And every 20 hours in a jet plane adds 0.1mSv to our total because of increased exposure to cosmic rays.

Nuclear power stations are much less dangerous than they might appear, as long as their control mechanisms work. Once the control rods are deployed to stop reactions - as happened immediately in Fukoshima in 2011 - then the radioactivity of the Uranium or Plutonium dies away quite quickly - by about 99.9% over a week. Therefore, although very high levels were briefly registered within the Japanese plant boundary, the level was reported to be only 10 millisieverts per hour or lower for most of the months and years after that crisis began.

> (The only proven deaths resulting from Chernobyl are therefore the c.50 that died at, or soon after, the time of the explosion, plus a dozen or so Belarus children who subsequently died of thyroid cancer, though many thousands suffered from that disease. The radiation plume that circled the Earth undoubtedly caused other deaths, but their random nature, and low rate compared with cancers caused by background radiation etc., mean that no sensible estimate can be made.)

Although it is non-ionising, **ultraviolet light** is still just about energetic enough to cause cancer. None of us can totally avoid all UV radiation, of course, but we should try to avoid prolonged exposure to sunlight, especially if we have fair skin.

A failure to avoid these precautions, together with the temporary depletion of the ozone layer, which let through more of the high energy UV radiation, has led to a doubling in the incidence of skin cancer in the UK, to about 5,000 cases a year.

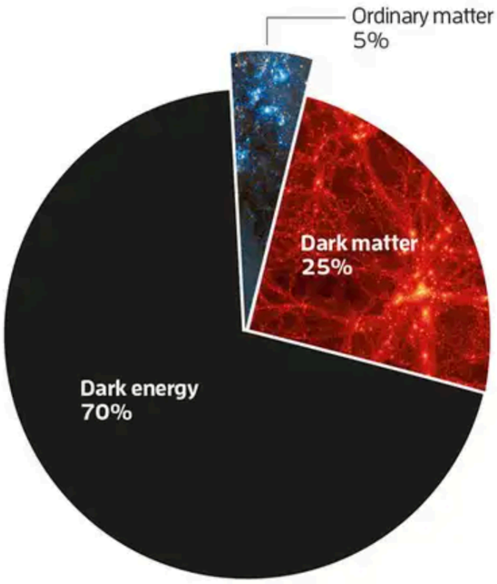
5. What is 'Matter'?

Mass and energy are ultimately the same thing (remember $E=mc^2$).

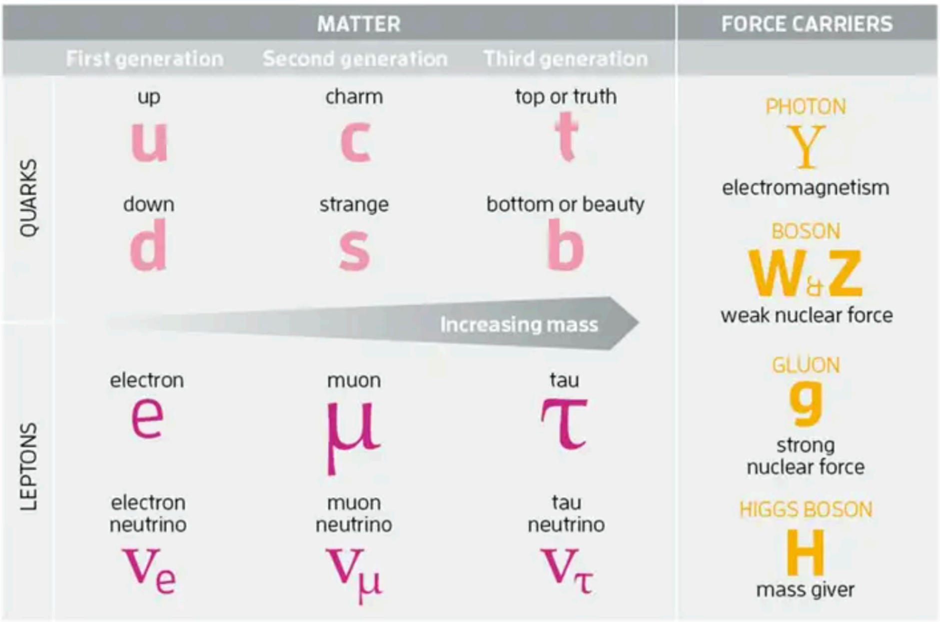
Bearing this in mind, scientists have shown that ordinary matter - gas, stars, planets and galaxies - comprise only **5%** of the Universe.

Dark energy makes up about **68%**, and dark matter - which does not reflect or emit detectable light - accounts for **27%**.

(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.)



Normal matter, the stuff that we are familiar with, takes the form of atoms and molecules. But atoms are in turn comprised of subsatomic particles.



All ordinary matter consists of **quarks** and **leptons** bound together by at least five messenger particles called **force carriers**. (A sixth - gravitons - may exist but they have yet to be detected.)

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

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. These do not occur in nature but can be manufactured in a collider.

6. Geology

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.

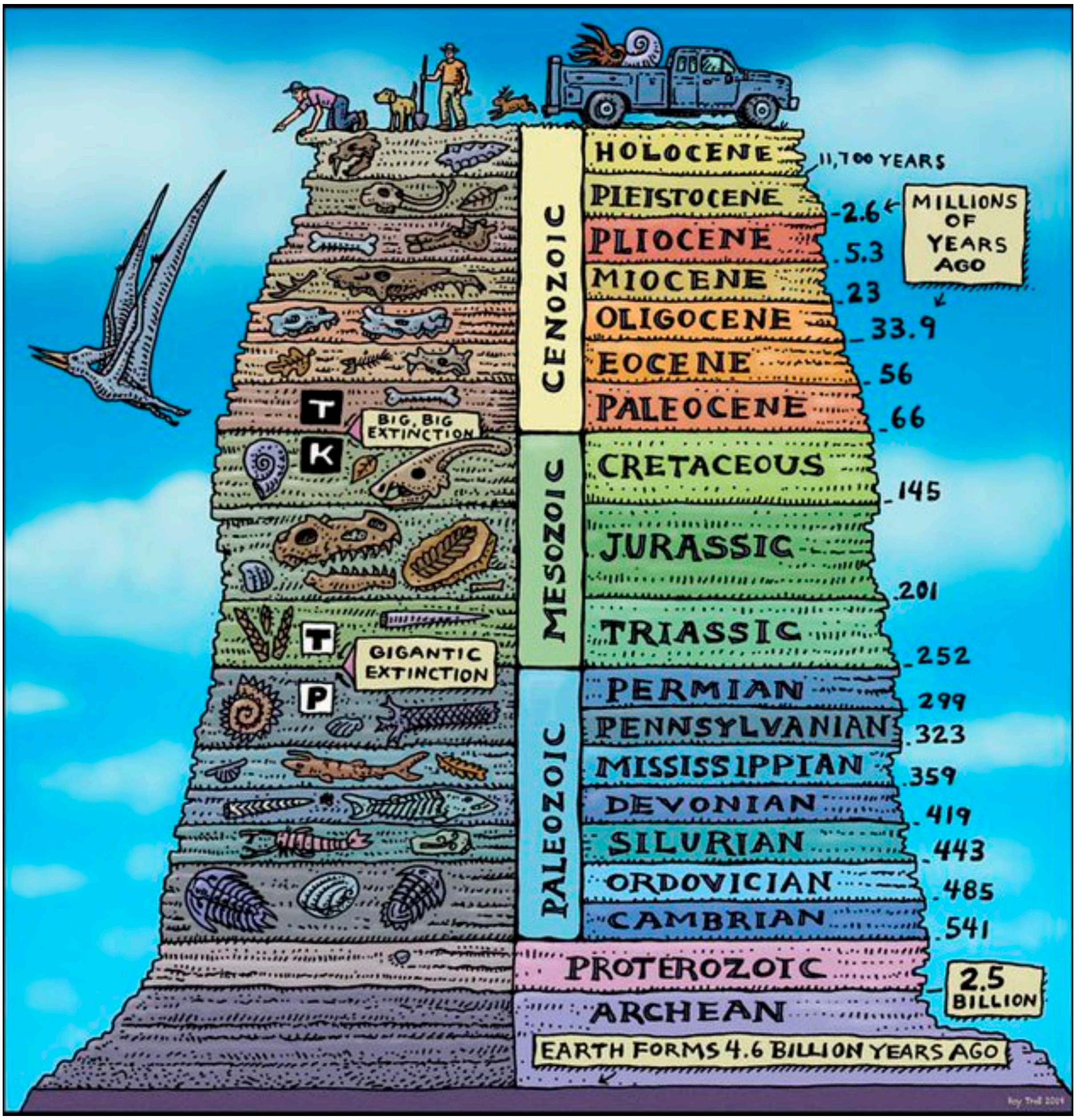
- Sand on a beach and mud on a river bed creates e.g. sandstones.
- Marine organisms create limestones, inc. chalk.

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.

Here is a nice chart showing the geological time scale, with ***Periods*** down the middle and ***Epochs*** on the right. Some believe that human impact on the planet means that we have entered a new epoch - the Anthropocene.



7. 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 began with simple eukaryotes and ended with homo sapiens. There is a detailed list at Annex C.

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.

Here is a nice image which neatly shows the tiny size of viruses and other very small particles. (As of 2023, the world's best mass producer of advanced chips in the world is now making 3-nanometer transistors. The size of the Zika virus, the smallest thing in this image, is 45 nm.)

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Annex A

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}	(a thousand)
mega	M	10^{6}	(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 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 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 single computation such as an addition or multiplication. Flops per second is therefore 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 can be reduced to SI units. Here are some examples of such ...

Derived Units

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.

As an aside:-

- The rate of change of position is *velocity*.
- The rate of change of *velocity* is *acceleration.*
- The rate of change of *acceleration* is *jerk*.

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 $6.67 x 10^{-11}$ 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.

> Note 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 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).

Other Data

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.

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.

Wavelengths & Frequencies:- 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 light (indeed, the speed of all radiation) in a vacuum is 3 x 10^8m/sec. (It goes more slowly 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.

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!

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 *oganesson* which has 118 protons.

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Annex B

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
$9.46x10^{15}$ metres = 1 light-year
$3.086x10^{16}$ 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

Alcohol

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).

$1.6x10^{-19}$ joules = 1 electron-volt (the energy gained by an electron accelerated through an electrostatic potential difference of one volt)

1 GeV = 10^9 x $1.6x10^{-19}$ joules = $1.6x10^{-10}$ joules = 1.78 x 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

Annex C

Our Evolutionary History

Richard Dawkins & Yan Wong's *The Ancestor's Tale* summarises the order in which our living relatives branched off the evolutionary line.

Evolution began with simple **eukaryotes.** The principal departures were as follows:

> Various more complex eukaryotes, inc. seaweeds, slime moulds, some amoeba, were the first to 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 then left, followed by ...
> Corals, sea anemones, jellyfish
> Acoelomorph flatworms (leaving animals with body cavities and anuses)
> Worms, insects (beetles, flies, crickets – 6 legs), centipedes (lots of legs), 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:
>
> This left **bony animals**:
>
> Coelacanths were next to branch off, followed by lungfish, leaving …
>
> **Tetrapods,** which are vertebrate animals having four limbs.
>
> > Note that snakes and other limbless reptiles and amphibians are tetrapods by descent.
>
> Subsequent departures were
>
> **Amphibians**: frogs, toads, salamanders, newts
> **Birds** and **reptiles** inc. dinosaurs, crocodiles, lizards, snakes, turtles - leaving ...
>
> **Mammals**:
>
> Marsupials then departed, leaving placental mammals which split off in the following order:

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

END