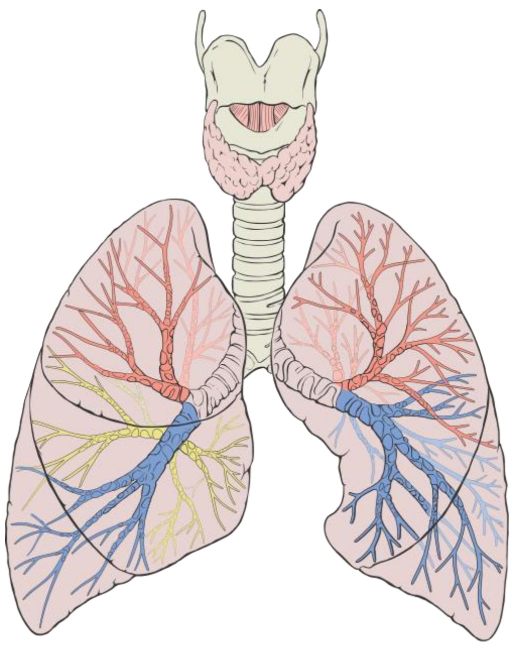
The Breath of Life

John S. Reid

Part 1: *Blood and tears*

This section has been prompted by reflections on smoking, which does pollute the local atmosphere but that's not really why I'm writing it. If you smoke, logic probably won't convince you to give it up. If the density of smoke in your lungs were repeated in the room you're in, you probably wouldn't be able to see the far wall, the smoke alarm would long since have gone off and general evacuation procedures would be bringing the emergency services at full tilt. However, that's a logical reason for not contaminating your lungs, as is the argument that you're much more likely to get cancer in later life, or obstructive pulmonary disease or prematurely age or a good number of other unpleasant later life afflictions. Indeed, smoking reduces life expectancy by some 10 years, a fact that rises into consciousness the older you get. I had the misfortune of visiting a heavy smoking relative on several occasions in her later life. Her house always stank of stale cigarettes. She could hardly move from her chair towards the end and the last few months of her life were spent in the alien surroundings of a rest home, frequently breathing with the help of an oxygen cylinder, in pain relieved by morphine and still wanting a fag. Who said smoking wasn't addictive? It was a really sad and distressing end for a bright lady who was the first in my family to go to University. However, that's all part of the logical reason for giving up smoking and smokers will probably ignore the message.

What I wanted to write about was the purpose of breathing. We live minute by minute through the circulation of our blood. Bright-red clean blood courses out of the left ventricle of our heart, through our arteries and spreads out from thick vessels to thin ones, bringing energy, food, repair mechanisms and much more to almost every cell in our body. The dirty blood, now dark purple with waste products and spent haemoglobin, returns through our veins. What cleans out these products and restores our blood to its bright-red working self? Breathing is the answer. Our lungs are an amazing organ in which the venous blood pumped from the right ventricle of our heart is divided ever more finely into thin capillaries that come very close to the highly divided surface of the lungs. Likewise, our air passage bifurcates and then divides into ever finer passages within the mass of the lungs, ending in a vast multitude of microscopic little grape-like sacks. Deep within the mass of tiny passages, in these tiny sacks air meets blood and the miracle of physical chemistry is wrought that cleans the blood. Oxygen re-enervates the haemoglobin, carbon dioxide passes out into the lungs. It all happens in seconds and then we breathe out again, hardly noticing the effort.



Lungs: courtesy Wikipedia

How often do you ever think about this almost miraculous life sustaining process, simple in its broadest description but highly complex in detail? Probably never. A pity, particularly if you smoke. Clogging up the tiny interstices of both lungs at once with smoke particles and condensates is a steep price to pay for five minutes of relaxation. It affects your blood, your whole body, toes to brain, not just twenty years into the future but now. Your body copes, sort of, because you've spare lung capacity over what you need in your resting state, when you're young and healthy. The damage, though, is being done with every cigarette. Your lungs are being turned from a vibrant pink organ to the ashen grey sponge that may end up in a plastic bag in the post-mortem disposals bin. I can tell you from experience that in later years even the healthy will value all the lung capacity they have got and will wish for a bit more. Being permanently short of breath is a life sentence with no remission.

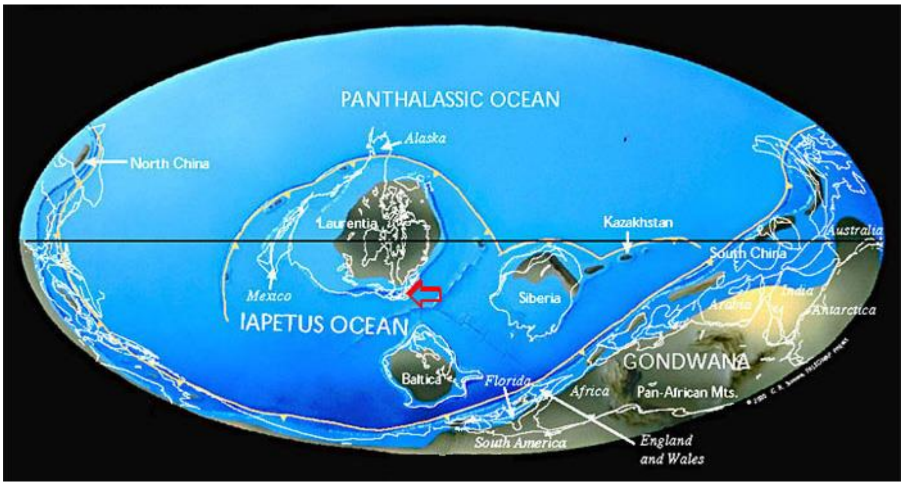
Age doesn't necessarily bring wisdom but it does bring experience. My experience, both personal and from seeing those I know is "don't mess with your lungs". You will need them. Our lungs face plenty of natural threats: regular strains of influenza have killed millions, yes millions, in the past couple of decades; MERS and SARS were more lethal when once infected but were contained on a world scale. There are plenty of others: bronchitis, pneumonia and as I update this, COVID-19 has reached pandemic proportions. We live in a hazardous world whether we like it or not and indulging in poisoning our own lungs doesn't seem to me a bright choice. I'm not really into preaching. The world has got too many preachers for comfort but if you smoke you probably do so partly because of peer pressure; it's what some of your friends do, so you've already succumbed to subtle persuasion. You're more likely to give up smoking if several of your friends agree to do it with you but even if a single person who reads this thinks about the miracle of breathing and stubs out their fag for the last time then the lesson that my relative failed to learn the hard way, and paid for with her life, will have been worth passing on. If you're still smoking, you've made the wrong decision on one of life's big choices.

Part II: *Demons and angels*

It's fashionable these days to demonise the production of carbon dioxide. We should be careful. More than 7 billion people as I write breathe out air with 100 times the CO_2 content of the air they take in. They do that perhaps 10 times a minute. Our exhaled breath has some 5% less oxygen than the air we inhale. I'm sure the figures are not hugely different for many other land animals. Life that does this is not sustainable on its own. The oxygen in our atmosphere would run out. Well before that, concentrations of CO_2 in the atmosphere building up to over 10% would cause convulsions, coma and death, as has been found from accidents in enclosed spaces. If we are demons, there must be some angels that reverse what we do, converting carbon dioxide to oxygen. The angels are plants, cyanobacteria and some amoebae.

When the fossil record begins in earnest, some 541 million years ago, it quickly fills with sea creatures and, to be unscientific, seaweed. The land on Earth was rocky, sandy, dusty, muddy and pretty barren. A geologist's paradise perhaps but not so for the zoologist and certainly not for the botanist. There likely were mats of bacteria, amoeba, protozoa and other single celled life but no grass, ferns, bushes, trees or any of the plants I see stretching out from my window.

The plants I see are multi-cellular life that can grow upright on land and respire using carbon dioxide. It's the growing upright on land that took time to develop, for that needs roots, mechanical strength and a vascular system for moving nutrients internally, the plant equivalent of blood flow. Roots need soil containing organic matter as well as fragmented



Mollweide projection showing the whole Earth 514 million years ago. Most of the land is below the equator. The red arrow shows the location of what will become Scotland. Courtesy: Paleomap Project

rock. The mats of life mentioned above would have formed the basis of early soils. Land plants didn't evolve until the late Silurian and early Ordovician eras, some 100 million years into the main fossil record. Those early plants weren't really representative of the plants I see out of my window either. Flowering plants, conifers and hardwood trees didn't arise until some 250 million years ago. In a way, it's no surprise that plants are in some ways more physiologically complicated than us mammals, for plant respiration takes in both oxygen and carbon dioxide and uses both to produce energy in separate processes.

Photosynthesis, the conversion of CO_2 and water by sunlight into glucose and oxygen goes back very much earlier than the appearance of land plants. It had been discovered or invented (take your pick) by cyanobacteria around 2300 million years ago. That evolution lead to the Great Oxygenation Event which, over hundreds of millions of years, generated in our atmosphere a concentration of oxygen that rose from near zero to over 15% by 500 million years ago. That oxygen was in fact also necessary for plant life to colonise the land, for all life on land would be exposed to damaging ultraviolet from the Sun were it not for the ozone layer in the stratosphere. Ozone, O_3, is pure oxygen and is produced from molecular oxygen, O_2. Both land plants and us need the ozone shield.


Photosynthesis in the garden: photo JSR

Photosynthesis is our sustaining angel. The leaves of plants contain tiny controlled openings called stomata through which CO_2 can enter by diffusion and water and oxygen leave. They are limited to a percent or so of the total leaf area, for a plant can't afford to lose more water than it can take up from its roots. Plants use CO_2 through organelles within plant cells called chloroplasts, organelles that include green chlorophyll. Chloroplasts are recognised as incorporating the photosynthetic mechanism of cyanobacteria into the cellular material of the plant proper. The process is not simple and several Nobel Prizes in the 20^{th} century have been awarded for discoveries that have helped unravel how it all works.

The complexity of plant cells in some respects exceeds the complexity of animal cells. The 'humble vegetable' is not at all humble and thinking about it almost makes one not want to eat plants. Still, needs must. I digress. The net result of photosynthesis is to take in CO_2 and water and produce sugars and the energy transport molecule ATP, and to release O_2 into the atmosphere. Pretty well everything in biology is complicated (here speaks the physicist) and photosynthesis is no exception. The 'photo' reactions occur because chlorophyll absorbs light, usually sunlight. It is these reactions that create the oxygen and various other compounds, including ATP. Some of these other compounds are involved in further, light-independent, reactions that convert CO_2 to sugars and other useful stuff.

Why plants are particularly complicated is that most plant cells also contain mitochondria, the same (or similar) agents that convert oxygen, glucose and other ingredients to ATP that we have in our own cells. Mitochondria likewise incorporate DNA sequences, originally bacterial, that are different from those in our cell nuclei that control all other cell functions. Plants can also absorb oxygen through their roots and stems, making them more able to cope with damage than we can, for we can absorb oxygen through only one organ, our lungs. The complex respiration in plants is part of the reason why some plants can live a lot longer than any animals. Clearly photosynthesis shuts down with lack of light or lack of leaves but plants can keep going a long time using oxygen respiration. In the daylight, green plants produce more oxygen by photosynthesis than they need and this excess oxygen is released, to our benefit.

Since plants also take in oxygen, I'll add a paragraph on aerobic respiration that applies to both plants and us. The net result of some 25 reactions is to take glucose and oxygen and strip all the carbon from the glucose, creating CO_2 and water and energy. The currency of energy is the ATP molecule that allows a wide range of energy consumptive processes within cells to take place. Both plants and ourselves give off water vapour as a result of respiration, which is one reason we both need a regular supply of water. Indeed, the absorption of oxygen within our lungs actually takes place from solution on the lining of our lungs, so the oxygen in the atmosphere must first be dissolved. This process limits the uptake and is yet another reason we need water and why water vapour comes out when we breathe out. If the humidity is very low, water evaporation takes place too quickly and the organism, us or a plant, is in trouble. Plants tend to have waxy exteriors over most of their surface to prevent evaporation and some means of reducing evaporation when there is a need to.

It almost goes without saying that the CO_2 we breathe out has less energy that the O_2 we take in. Since plants do the opposite, the energy to do so must come from somewhere. It comes from the sunlight used. The conspicuous chlorophyll (there is more than one type) absorbs in the blue and red, which makes it appear green. As an energy conversion mechanism, photosynthesis is pretty poor, with a quoted efficiency of less than 1%. A few figures won't go amiss. A farmer's field of 10 hectares covers 10^5 m^2. During the growing season it might receive 300 W of solar energy per square metre on average for 10 hours a day in our latitudes (more nearer the equator). That's 3 KW hours of energy (about 10 MJ) per day per m^2, or a total of 3×10^5 kW h, equivalent to 10^{12} J, a billion Joules per field per day, which is indeed a prodigious amount of energy. Over the growing season of 100 days, you can multiply this by a factor of 100. How prodigious is this? In food terms, a reasonable diet of 2400 Cal per day has an energy content of 10 MJ. So the solar energy falling on the farmer's one field has the energy equivalent of enough food for over 25,000 people for a year. In reality, one field that size could do not much more than keep a few families going for a year. In terms of the use of atmospheric gases, this is a bit of a digression but it shows that the whole photosynthesis process is not an efficient creator of useable energy. If we had photosynthetic skin, it wouldn't be much use in supplying our daily energy needs, even if we went around naked. OK, forget that image.

Our mitochondria can use oxygen transported throughout the body by our blood, without the need for daylight; chloroplasts reside on or near the surface of plants, for they need light. Plants grow upright so they can have a much bigger surface area than they would if spread on the ground. Looking at the blades of grass on the lawn outside my window, each must have at least 20 times the area it occupies on the ground, even though it has been cut. A large tree may have a million leaves. If each is 10 square centimetres, that's a surface area of 1000 square metres. Why do plants need big surface areas? The problem they face on land is that CO_2 is present only at a concentration of about 400 parts per million in the atmosphere. Oxygen concentration is 500 times larger. All life relies on the diffusion of gases as part of respiration. Diffusion is driven by differences in concentration. The bellows action of our lungs maximises the concentration gradient where it matters. Photosynthesising plants have no such aid and they have a much smaller CO_2 concentration to work with. The angels of photosynthesis have a difficult task.

It takes vast areas of green leaves to convert CO_2 back to oxygen. That is something mankind shouldn't forget. In spite of all the oxygen breathing that goes on in the world, and other natural processes that use oxygen, oxygen levels in the atmosphere have remained pretty constant for millions of years, thanks to this vast amount of plant life. So what is mankind going to do when our oxygen breathing offspring travel the solar system to planets and moons that have no plant life whatsoever, which is all the rest at the moment?

JSR