# 4

# The Data of Science

## Introduction

In teaching the content of our science syllabi, we must ensure that it is integrated into the story of *Creation, Fall and Redemption*.[1]

**Creation:**

- Our God-given task to care for, develop and shape the earthly creation, but humbly and wisely for we are God's servants who are accountable to Him for all that we do.

- The natural world as God's loving provision for us.

- The rich diversity of roles ('natural functions') that created things do, or can, fulfil to sustain God's world, and aid us in our cultural task.

**Fall:**

- God's judgement and our continuing sin have spoilt God's good creation.

- Our cultural development has followed some disruptive and destructive paths.

- Our true calling and task may now be hindered or blocked.

**Redemption:**

- Discovering our duties and responsibilities in the network of relationships in which we and other created things are embedded.

- Discerning the distortions and abuses that affect the development of God's creation.

- Working for the restoration of true roles, the healing of brokenness, and the reconciliation of all those who are alienated from God, from each other, and from the world.

In the secular textbooks and syllabi the presentation of the natural world reflects our society's faith in the idols of *science, technology, and economic growth*. Thus consideration of any item almost invariably begins with selected characteristics or properties, and then passes on immediately to human industrial uses (including medical, agricultural, and domestic). Such a solely human-centred, industry-dominated approach tacitly undergirds the secular humanist view of a purposeless universe, i.e. of a universe in which the only purposes are those arbitrarily given by human beings.

There are much better ways of teaching science that utilise the themes of Creation, Fall and Redemption. The following examples are given to illustrate the possibilities.

# Part I: Calcium

## 1 Elemental Design

This world is God's creation. If we find that it contains around a hundred chemical elements,[2] then, on the basis of creation, we assume that this number of elements is needed for the world that God has created. We assume, in other words, that each element is *special* and has that unique combination of properties that fit it for specific roles and relationships in God's world. We then interrogate each element and system as outlined in the *Introduction* above.

In this discussion on calcium we will consider two major areas:

- the design of calcium and its compounds for specific roles in God's world;
- the rich diversity of roles fulfilled by calcium's major compound. Our survey will also indicate how those roles have been disrupted and corrupted by human greed, and what can be done to restore *shalom*[3] to this area of creation.

## 2 Calcium in the World

Calcium is one of the *alkaline-earth* elements[4] that occupy the second column of the periodic table. These elements have a strong tendency to be lose electrons and form two-valent ions, $M^{2+}$. Calcium itself is very widely distributed in the Earth's crust and is the fifth most abundant element (two atoms out of every 100, = 3.6% by mass) and the third most abundant metal (after aluminium and sodium). It is also the third most abundant positive ion in sea water (after sodium and magnesium). In the human body it is the most abundant metal, accounting for nearly 2% of body weight, mostly (*c*. 99%) in the bones. Total calcium content has been estimated to increase from around 28 g (0.8% body weight) at birth to about 1 kg (1.9% body weight) at maturity.

The average UK adult intake of calcium is over 800 mg per day which is above the 700 mg which is currently regarded as the average requirement.[5] However, it is highly probable that some school girls have intakes that do not meet their needs. In the average British diet, milk and other dairy products provide the major supply.[6] White bread, cereal products and some vegetables also provide substantial amounts and in some areas the water supply is also an important source. Although current adult intake is adequate there has been a 20% decline over the last 30 years due mainly to a fall in the consumption of milk and white bread.[7]

Calcium has many important roles in the physical and biological worlds. Here we will look briefly at some of the amazing structural and physiological functions that the element fulfils.

## 3 Structures

Calcium (together with magnesium) is a key element for the *dynamic* structures of both planets and organisms. Elements with this role must provide some soluble compounds (e.g. calcium hydrogen carbonate, calcium chloride, calcium nitrate), so that the element is readily available and can be transported in rivers and body fluids. They must also, of course, provide some hard, insoluble solids (e.g. calcium carbonate, hydroxyapatite[8]), so that hard parts can be built up, both planetary - i.e. sedimentary rocks [9] - and biological - e.g. corals, shells, bones and teeth.

The two-valent ion ($Ca^{2+}$) is important for linking or cementing other substances, in both the inorganic realm (*eg*, cementing sediments) and in the organic (*eg*, cell walls, blood clotting, precipitation of milk protein in the stomach) (see also **4** below). Commercial cements are also, of course, calcium products - chemically they are mixtures of calcium silicates and aluminates together with some sulphate.

## 4 Physiology

Calcium's physiological roles are both passive and active. *Passively*, it is an important co-factor[10] for many enzymes. *Actively*, it acts as an intracellular messenger and signal. The details of this latter role are so fascinating that a brief summary follows.

Because calcium is an essential structural component of bones and teeth, it is easily assumed that it is a harmless and nutritious element. Paradoxically, it is actually very toxic in the free state (i.e. as $Ca^{2+}$). The level of $Ca^{2+}$ inside cells (i.e. *intra*cellular) has to be kept very low, because a concentration of calcium ions exceeding even one part in a million is lethal.[11] The reason is that cellular processes depend on soluble organic phosphate compounds (such as ATP). Calcium phosphate, in contrast, is *very insoluble* (see section 4 above). If the $Ca^{2+}$ level was not kept very low, phosphate would be rapidly removed from circulation within the cell as insoluble calcium phosphate. The life of the cell would come to an abrupt end. Because calcium is so abundant, the result is that the concentration of free calcium inside cells is about 15 000 times less than outside[12] and about 100 000 times less than in seawater. But this very steep gradient is essential to the body's use of the calcium ion as a highly sensitive intracellular messenger.

The cellular $Ca^{2+}$ concentration can be abruptly raised for signalling purposes by briefly opening channels in the cell membrane or in the membrane of an intracellular store (mainly the *endoplasmic reticulum*). The rise in the intracellular calcium concentration then stimulates a response event such as the aggregation of cells, the degradation of muscle proteins, the secretion of special compounds, the transformation of cells, or cell division.

The high sensitivity is the reason why calcium is at the centre of many processes in animals that 'go off suddenly' (e.g. muscle contraction, nerve conduction). The cell calcium concentration changes are triggered by physiological stimuli such as hormones or neurotransmitters.[13]

Another reason why calcium is such a fantastic intracellular messenger is that $Ca^{2+}$ can bind tightly to proteins by forming 6-8 coordination bonds to oxygen atoms.[14] It can thus induce large changes in the shape (and thus function) of proteins.

The structural and physiological roles of calcium have traditionally been considered independently and there is still much to be learnt about the interactions between them. Bones, for example, are not inert or 'dead'; they contain many bone cells, blood vessels and nerves and form a dynamic biological system. Bone tissue is constantly being remodelled, with bone continually being removed and reformed in a cycle that lasts between four and six months.

In women the accelerated bone loss after the menopause is due to an increase in bone turnover. This is the outcome of an imbalance between bone formation and bone resorption which, in turn, results from a deficiency of the hormone oestrogen.

The mineral crystals in bone are very small with a large surface area, so that bones are effectively large ion-exchange columns, i.e. when necessary, bones are able to exchange their ions for other ions in the surrounding medium.

The interrelation between structure and physiology is evident in the fact that all vertebrates (fish to mammals) that have true bone, also have calcium ion concentrations in their body fluids that remain remarkably constant at a level in the range 50-65 mg per litre. This level is extremely important for the maintenance of the normal functioning of nerve and muscle, for the integrity and permeability of cell membranes, for blood clotting, for vision and for heart function.

## 5 The Uses of the Main Calcium Mineral: Limestone

In textbooks and syllabi, limestone (the commonest form of calcium carbonate) tends to be considered only in relation to industry-centred uses, i.e. as an aggregate[15] and as a chemical feedstock (Table 4.1). But limestone fulfils a wide variety of roles, so much so that it also has great value left where it is (Table 4.2).

In the south-west the Somerset Mendip Hills are a major limestone area. Rain falling there passes through hot limestone beds deep underground, to well up again in the Roman Baths at Bath. The Mendip limestone *aquifer* [16] provides 90 billion litres of drinking water each year to hundreds of thousands of people in Somerset and Bristol. But 20 million tonnes of limestone is now quarried each year threatening to disrupt the aquifers as quarries sink ever deeper beneath the water table. By 1989 five of the Mendip springs, once large and clear, had shrunk or been polluted. Even the famous Bath springs are now at risk. The quarrying also causes permanent loss of farmland, irrevocable landscape changes, an endless procession of heavy trucks through country lanes and villages, and much noise and dust pollution. Overall, it can be cogently argued that hard limestone is more valuable *in situ* than as a quarried stone (Table 4.2).

## Table 4.1 Industrial Uses of Rocks[17]

| | Hard Limestone | Granite | Basalt | Gritstone |
|---|---|---|---|---|
| **Cost of extraction** | Low | High | High | Very high |
| **Common aggregate** (e.g. for concrete) | Good | Good | Good | Good |
| **Base aggregate** (e.g. for roads and railway tracks) | Very good | Good | Very good | Good |
| **Wearing course** (e.g. road surfaces) | Not used | Medium | Good | Very good |
| **Quarry wastage** | Low | Medium | High | Very high |
| **Building stone** | Used | Useful | Rarely used | Used |
| **Chemical feedstock** | Yes | No | No | No |

## Table 4.2 Value of Rocks in their Natural Position[18]

| | Hard Limestone | Granite | Basalt | Gritstone |
|---|---|---|---|---|
| **Water resources** | Good | No | Poor | Occasional |
| **Landscape** | Very good | Very good | Good | Very good |
| **Special attractions** | Many | Many | Many | Many |
| **Caves** | Yes | No | No | No |
| **Walking / climbing** | Very good | Very good | Good | Very good |
| **Open space** | Yes | Yes | Yes | Yes |
| **Archaeology** | Yes | No | No | No |
| **Mines / minerals** | Many | Many | Few | Few |
| **Agricultural soil** | Good | Poor | Very good | Poor |
| **Fauna / flora** | Very diverse | Limited | Good | Limited |

**NB**: Hard water from limestone areas neutralises acid rain whereas soft water from peaty areas can form carcinogens when chlorinated.

# 6 Conclusion

Calcium and its compounds are far more than raw materials for human industrial uses. A teaching that celebrates the rich diversity of their roles in creation is quite simply better science teaching.

Such teaching undermines the still popular myth that science (and science teaching) is neutral (i.e. free from any 'values') It helps our children to recognise and subvert the idolatries that dominate our society. Above all such teaching is far more relevant and meaningful to them. In locating the curriculum material in the narrative framework of *Creation, Fall and Redemption*, Christian science teachers are simply restoring it to the only location it truly has.

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# Part II: Atmosphere and Ocean

## 1 The Planetary Systems

On the basis of creation, we assume that all the systems of God's world are *special*, and have those unique combinations of features and properties that fit them for specific roles. We then interrogate these systems as outlined in the *Introduction* above.

In this discussion we will consider three areas of interest:

- the design of the Earth's planetary systems that allows the maintenance of the 'impossible' chemical compositions of the present atmosphere and ocean;

- the implications of these design features for our understanding of environmental pollution, planetary chemistry, and the origin of life;
- other design features of the ocean-atmosphere system.

## 2 The High Reactivity of Oxygen and Nitrogen

The most remarkable thing about the present compositions of the atmosphere and the oceans is that they are physically and chemically quite impossible. They would quite definitely not be expected by chemists. The equilibrium compositions expected under Earth conditions for atmosphere and oceans are quite different from what we actually find (Tables 4.3 and 4.4).

### Table 4.3 The Atmosphere of the Earth with and without Life[19]

| Item | Earth (minus life) | Earth (today) | Venus | Mars |
|---|---|---|---|---|
| **Gases** (% volume) | | | | |
| Carbon dioxide | 98 | 0.03 | 96.5 | 95 |
| Nitrogen | 1.9 | 78 | 3.5 | 2 - 3 |
| Oxygen | 0.0 | 21 | trace | 0.1-0.4 |
| Methane | 0.0 | 1.7 ppm | 0.0 | 0.0 |
| **Sea-level pressure** (atm) | 60 | 1.0 | 90 | 0.008 |
| **Surface Temperature** ($^oC$) | $290 \pm 50$ | 15 (-80 - +40) | 480 | -50 (-140 - +20) |

### Table 4.4 The Oceans of the Earth with and without Life[20]

| Item | Earth (minus life) | Earth (today) |
|---|---|---|
| **Chemicals** (mass %) | | |
| Water | 85 | 96.5 |
| All salts | 13 | 3.5 |
| *Sodium nitrate* | *1.7* | *trace* |
| **Acidity** | Acid | Alkaline |

The oxygen and nitrogen in the air are very reactive elements. Their overwhelming tendency is not to remain free (uncombined, 'unfixed') as the gaseous elements, but to combine with (oxidise) other elements until they attain their most stable forms. Under Earth's warm, moist conditions, the stable form of oxygen is oxides and the stable form of nitrogen is nitrates. The relative stability of their two-atom molecules ($O_2$, $N_2$) masks their high reactivity and creates a quite misleading impression. But there is sufficient energy of the right kind coming from the sun to enable the molecular bonds to be broken, allowing oxygen and nitrogen to display their true reactivity.

We must remember to distinguish between the amount and kind of energy. If the Sun's surface temperature was only 550 $^{o}$C (instead of the actual 5500 $^{o}$C) and the Earth was much nearer, then the Earth's climates would be very similar to what they are. But the predominantly long wavelength (low energy) radiation would be quite insufficient to break chemical bonds. There would be, for example, no photosynthesis. Life would be impossible.

We inhabit a *living* world in which organisms constantly cycle nitrogen and oxygen, maintaining the levels of the free gases in the atmosphere. But let us imagine what would happen if all organisms were removed from our planet. In the absence of life, various normal chemical processes would steadily transform the Earth. Oxygen would slowly disappear from the air as it oxidised various inorganic and organic materials. Reduced iron (Iron II, or ferrous iron) would become rust (Iron III, or ferric iron), sulphide ($S^{2-}$) would be oxidised to sulphate ($SO_4^{2-}$) and organic material to carbon dioxide and water. Lightning flashes would enable nitrogen to combine with oxygen to form nitrogen oxide gases. These oxide gases would react with water and hydroxyl radicals to form nitric acid which would fall in rain. The acid would soon be neutralised to form nitrates which would end up as nitrate ions dissolved in the oceans.[21] With no organisms to reverse these flows, nitrogen and oxygen would be locked away.

## 3 Acid Rain, Planets and the Origin of Life

From being slightly alkaline (pH 8.1-8.4), the sea would become acid, releasing carbon dioxide from carbonate rocks (e.g. limestone - 10% of all sedimentary rocks). Rain (normally very slightly acidic (*c.* pH6) due to $CO_2$ buffered by traces of ammonia[22]) would become much more acidic (~ pH3), releasing further $CO_2$ from rocks and leaching more nutrients from soils into the lakes and seas. Under such acid conditions, most mineral nutrients in the soil become unavailable to plants. Aluminium (normally bound in insoluble soil complexes) is leached out into solution in the rivers, lakes and seas where it is poisonous to living organisms. This provides a useful insight into the problems created by *acid rain*.[23]

When equilibrium is eventually reached, the oceans would be hot concentrated salt solutions containing toxic amounts of nitrate. The Earth would then have a hot, high-pressure, carbon dioxide atmosphere like its sister planet Venus. Venus' hostile conditions are now more than just an interesting astronomical fact to be learnt!

Mars has very similar conditions, but without the high pressure, probably because it is a small enough planet for asteroid and comet impacts to have blasted most of the original atmosphere away into space.

James Lovelock sums it up well:

> To describe the burgeoning life of our planet as improbable may seem odd. But imagine that some cosmic chef takes all the ingredients of the present Earth as atoms, mixes them, and lets them stand. The probability that those atoms would combine into the molecules that make up our living Earth is zero. The mixture would always react chemically to form a dead planet like Mars or Venus.[24]

The 'origin-of-life' experiments (1953 onwards) utilised not the type of atmosphere to be expected on a lifeless Earth – with a predominance of $CO_2$ and absence of free oxygen – but a reducing atmosphere based on that of the giant outer planet, Jupiter, i.e. mainly hydrogen and helium with a little ammonia and methane. The reason is clear. Even in an atmosphere without a source of oxygen, the accumulation of significant amounts of organic compounds is highly improbable.[25] In any kind of oxidising atmosphere it is effectively impossible.[26] Evolutionists have assumed that life originated under reducing conditions and only gradually produced and adapted to an oxidising atmosphere. However the weight of evidence now suggests that the Earth has always had an oxidising atmosphere. The popular belief in a 'primeval soup' of organic chemicals from which life originated belongs firmly in the realm of fairy tales. The problems facing theories of the chemical origin of life are immense.[27]

## 4 General Functions of the Ocean-Atmosphere System

Amongst other things, the oceans act as

- a reservoir of dissolved gases to regulate the air;
- a vital part of the global (ocean-atmosphere) 'steam engine' that transforms sunlight energy into the air and water movements which distribute heat around the Earth.

The atmosphere is heated at the bottom (surface of the Earth) producing vigorous convection currents which distribute the heat horizontally. The oceans have a much greater capacity for storing heat and actually heat the atmosphere more than the sun's rays do. The enormous specific heat capacity of water means that it takes a lot of solar heating to warm the oceans and once warmed they are slow to cool. This protects us from sudden climate changes and allows ocean currents such as the Gulf Stream to carry solar heat from the tropics towards the poles. The top three metres of the ocean contain as much heat as the 100 kilometres or so over which the atmosphere extends. As warm water flows from the tropical waters of the Atlantic towards the North Pole, about $10^{15}$ watts of heat is released into the atmosphere, equivalent to the output of a million power stations. This heat warms the eastbound winds across the Atlantic and explains why Europe experiences much milder winters than the East coast of North America.

Circulation currents, which can extend over thousands of kilometres, mix warm water at the surface with cold water down to depths of hundreds or even thousands of metres. These large circulations, such as the Gulf Stream, are driven by the force of wind moving over the ocean surface. But while the land and air can change temperature in a matter of hours, the oceans take their time. At their present rate of flow, some deep currents take centuries to transfer heat from one side of the world to the other.

Without this ocean-atmosphere system, the winter pole (*eg* north polar lands in January) would experience temperatures close to absolute zero, whilst the summer hemisphere (*eg* Australasia) would be extremely hot.

## 5 Conclusion

The atmosphere and oceans are far more than chemical mixtures which are a source of raw materials for human industrial uses. Indeed, to teach air or seawater as just chemical mixtures, is to destroy their meaning and to fail to promote understanding of their chemistry and its significance. A teaching that celebrates their place in the scheme of creation is far more interesting for our students. It also exemplifies a richly holistic approach that will commend itself to science teachers everywhere.

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# Part III: Designing Cells

## 1 Why are Animal and Plant Cells So Different?

In secular textbooks and syllabi the treatment of biological topics tends to reflect our society's commitment to evolutionary naturalism. The discussion of cell structure and function, for example, is generally reductionistic, i.e. primarily a list of the normal cell components with their individual functions. This approach is totally dominant when we come to consider the major differences between plant and animal cells. Almost all texts simply inform the student of the differences between these types of cell without any discussion of the reason for such very different cell designs. The very act of not addressing these (from our Christian perspective, very obvious and important) questions is a *null curriculum* which undergirds the overall impression of an essentially undesigned, chance-dominated universe.

But there is a much better way. If the biological world contains some very different cell designs, then, on the basis of creation, we assume that these different designs are demanded by the different life-patterns of the organisms which have them. We expect, in other words, that each design is *special*, and has that unique combination of features and properties that fit it for specific roles and relationships in God's world. This paper examines cells from that perspective.

## 2 Requirements for Efficient Cell Functioning

Effective cell functioning - especially all the biochemical reactions with their specific enzymes - requires an ordered and fairly constant internal environment. In other words, the cell interior must be maintained within tight limits of temperature, acidity, degree of oxidation and salinity etc. Cells also require adequate concentrations of key metabolites (organic compounds). Without these concentrations, cellular reactions would be too slow to sustain life. Cells must therefore be protected from the highly variable conditions outside. In other words, they need clear boundaries. But cells are *steady state systems* that function (live) by constantly exchanging materials with their environment. The boundaries must be permeable. Cells cannot, therefore, have *passive* boundaries that let anything through. Their boundaries must be *actively* and *selectively* permeable.

Cells must retain the organic molecules produced by metabolism.[28] However, this creates an excess of osmotically active material inside the cell and thus an osmotic problem - water tends to flow in.[29] In theory, this problem could be solved in various ways:

**(1)** Rendering the cell membrane watertight (completely impermeable). This is untenable, because cells are steady state systems that function (live) by constantly exchanging materials with their environment.

**(2)** Installing a pump to constantly discharge the excess water. This is costly in terms of energy, so it is probably viable only for unicells, e.g. the *contractile vacuoles* of freshwater protists, such as the famous *Amoeba*, *Euglena* and *Paramecium*.

**(3)** Synthesising a special osmotic agent when the cell needs to decrease water potential[30] and expelling or polymerising it when the cell needs to increase water potential. This would give regulatory autonomy, but is energetically wasteful. The agent would have to be distinct from nutrients and metabolites, inert to general metabolism and electrically neutral. No example appears to be known.

**(4)** Actively pumping other osmotically active substances such as ions. This is energetically wasteful and tends to interfere with general metabolism. No organism is known to use it as its main method, but some appear to use it as a supplementary mechanism. *Amoeba* is thought to actively adjust the ions in its cytoplasm so that water entering by osmosis is reduced to a level that the contractile vacuole can handle efficiently, i.e. keeping overall energy expenditure to a minimum.

**(5)** Surrounding the active cell with a non-selective open mesh cage which can resist cell pressure. This can be illustrated by blowing up a balloon inside a strong polythene bag which limits its size. The traditional football with its rubber bladder inside a strong leather case is another good example of the principle. For organisms, the cage must be able to resist the hydrostatic pressure of a cell maintained in an 'inflated' condition. Regulatory mechanisms are then required to maintain the excess pressure. Energetically, it is a low-cost solution, but this also limits it to single-cell organisms or to larger inactive organisms, i.e. those with low levels of energy expenditure.

**(6)** Maintaining an osmotically constant environment and obtaining fine control by pumping in or out readily available inert constituents of that environment. This solution allows high levels of energy expenditure. The disadvantage is that it is energetically costly and requires a much higher degree of tissue and organ differentiation in order to provide for the osmotic regulation (osmoregulation) of the tissue fluids. Nevertheless, it is the necessary solution for all larger active organisms (which, in any case, must have a high degree of tissue and organ differentiation).

## 3 Conclusion

Plants are relatively inactive organisms which (green plants) are able to make their own food. Consequently for them solution **(5)** is best. The cells are encapsulated in permeable cellulose boxes (the plant *cell wall*) which can withstand high pressure. In fact, plant cell walls can withstand up to 50 atmospheres pressure, whereas animal cells typically burst at very low pressure differences. However, this solution does mean that plants have a high demand for water, especially at times of peak activity.

For animals, as typically active organisms, solution **(6)** is best. The osmolarity of the tissue fluid is carefully regulated and then cell *cation* [31] pumps provide the fine control. Animal cells, one may say, are osmometers.

The radically different designs of animal and plant cells reflect the different solutions to the osmotic problem that are appropriate to organisms with very different modes of life and levels of activity. Any teaching of plant and animal cells that fails to discuss their design is quite simply poor teaching. It also misses a wonderful opportunity to bring a traditionally dry topic to life.

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## Notes

[1] See Chapter 1**,** *Science in Faith***,** Parts I and II.

[2] There are 94 naturally occurring elements, of which 13 occur only in radioactive forms. Of the latter, 9 occur only as traces. Elements 95 to 109 have been created artificially, but are very short-lived. The production of elements 110-112 has been claimed, but not (as of March 1997) verified.

[3] *Shalom* is a Hebrew word that has no simple equivalent in English. It refers to righteous and harmonious relationships in every area of communal life.

[4] In order, these are magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba) and radium (Ra). Historically, an 'earth' was a non-metallic substance that is nearly insoluble in water and unchanged on heating. Here it is the oxides (e.g. CaO) which are clearly 'earths' and have an alkaline reaction.

[5] These figures are the *dietary* requirement. Overall only about 30% of the calcium in food is absorbed into the body. In other words, our body's actual requirement is about 200 mg per day.

[6] Out of an average daily intake of 800mg, *c* 250mg comes from green vegetables and the remainder mainly from milk and milk products.

[7] It should be noted that calcium in dairy products is absorbed well, whereas it is not absorbed so readily from plant foods.

[8] Hydroxyapatite is a common calcium phosphate mineral and the main inorganic component of bones and teeth. Since calcium is the only common metal that forms such very insoluble sedimentary compounds, calcium phosphate, in its many forms, is by far the most abundant inorganic compound of phosphorus.

[9] Limestone (calcium carbonate) is by far the most abundant inorganic compound of carbon and forms about 10% of the sedimentary rocks of the earth's crust (shales *c* 77%, sandstones *c* 13%). The wonder of stalagmites and stalactites depends on the interconversion of soluble and insoluble calcium compounds.

[10] Co-factors are nonprotein substances that must be present in suitable amounts before certain enzymes can act.

[11] This is comparable in toxicity to cyanide!

[12] The low internal concentration is maintained by a pumping mechanism which removes calcium from the cell.

[13] Neurotransmitters are small molecules that relay (or hinder the relay) of electrical signals to nerves, muscles, or glands.

[14] Magnesium ions cannot fulfil this role as they have little affinity for uncharged oxygen atoms.

[15] Crushed rock for, e.g., roads and railway tracks.

[16] A layer of rock or soil that is able to hold or transmit much water.

[17]Adapted from Table 1 in W. Stanton, Bleak prospects for limestone, *New Scientist*, **122** (1664), 13 May 1989, p 59. Note that commercial 'basalt' includes many dark igneous and volcanic rocks.

[18] Adapted from Table 2 in W. Stanton, Bleak prospects for limestone, *New Scientist*, **122** (1664), 13 May 1989, p 59. The many special attractions of hard limestone in the UK include Cheddar Gorge (Somerset), Bath Hot Springs, Wookey Hole caves (Somerset), Malham Cove (North Yorkshire) and Burren pavement karsts (County Clare, Ireland).

[19] Adapted from Table 2 in J.E. Lovelock, *Gaia: A New Look at Life on Earth*, Oxford: OUP, 1987, p 39 (Table 1.1 in J.E. Lovelock, *The Ages of Gaia: A Biography of our Living Earth*, Oxford: OUP, 1995, 2nd edn, p 9). 60 and 90 atmospheres are the pressures at 600 and 900 metres depth respectively in the Earth's oceans.

[20] Adapted from Table 1 in J.E. Lovelock, *Gaia: A New Look at Life on Earth*, Oxford: OUP, 1987, p 36.

[21] This is the scenario with abundant oxygen. In a $CO_2$ atmosphere without free oxygen, $N_2$ gas would be stable and abundant.

[22] The atmosphere contains on average only $10^{-6}$% ammonia, but the flux (rate of annual flow through the atmosphere) is 300 megatonnes, similar to that for nitrogen. Some ammonia is produced inorganically (occurring in the gases from some hot springs), but most is produced by organic excretion and decay processes.

[23] In an atmosphere dominated by oxygen, rain is *always* acid; the reference is to the *extra* acidity of rain falling from polluted air. This acid rain damages plants and sometimes also the natural ecosystems of rivers and lakes.

[24] J.E. Lovelock, *The Ages of Gaia: A Biography of our Living Earth*, Oxford: OUP, 1995, 2nd edn, p 24.

[25] In lifeless environments, organic compounds are destroyed as fast as they are made. See the books on the Origin of Life listed in Chapter 5, Section 8.

[26] 'Carbon dioxide is the kiss of death for organic chemistry.' (Jeff Bada cited by Jeff Hecht, A smashing start for life on Earth. *New Scientist*, **141** (1915), 5 March 1994, p 15.

[27] For literature on the origin of life, See chapter 5, Section 8, Origin of Life.

[28] Especially the *anionic* (negatively charged) compounds such as amino acids, organic phosphates, pyruvate, lactate and acetate.

[29] An aqueous medium surrounds all living cells in all organisms, regardless of whether they are terrestrial or aquatic, plant or animal. Therefore all exchanges between cell and environment take place in an aqueous medium.

[30] *Water potential* (represented by Greek letter *psi*, □) measures the net tendency of a system to donate water to its surroundings. If a cell has a lower water potential than its surroundings (e.g. because of solutes) then water will flow in and expand the cell if it is able to. Older discussions talked of *osmotic pressure* (which measures the effect of solutes on water potential) and this term is still used sometimes in animal physiology and medicine.

[31] Positively charged ions such as those of calcium and potassium.