Reflections

Science and the Human Condition *

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Introduction

Modern science began around the middle of the 17th century, it is just about 350 years old, it is very young. We can express its youth by saying that it spans just about 18 human generations. It is commonly agreed that it was inaugurated by Galileo and Newton. They saw that mathematics was the language of nature, and this language could be exploited most effectively in the description and analysis of nature. Indeed Galileo declared that the book of nature was written in the language of mathematics, and if we do not learn this language, we cannot read a single word of nature. More importantly we can say that while the preceding heroic era of Copernicus and Kepler was still descriptive (and this is no disparagement at all to their genius and achievements), it was only with Galileo and Newton that there was a transition to the understanding and explanation of natural phenomena. In the case of the life sciences, we may say that the corresponding point of transition was the publication of Charles Darwin's theory of natural selection. Galileo and Newton were concerned mainly with mechanics, astronomy, optics and of course mathematics as well. But they spelt out the agenda and showed the way for science to follow in succeeding centuries. One important and helpful factor in the philosophical background at that time was a liberation in the ways of thinking, a loosening of restrictions. As Max Born described it, "The distinctive quality of these great thinkers was their ability to free themselves from the metaphysical traditions of their time and to express the results of observations and experiments in a new mathematical language regardless of any philosophical preconceptions".

It is this modern science that I have in mind in the title of this talk. At this point let me give you some idea of the ground I wish to cover, so that I can carry you along with me. At first I will describe the picture of nature achieved through modern science, through assemblies of carefully selected facts. The aim is to convey to you, admittedly rather briefly, what we now know at three levels: the World of the Very Large; the World of the

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Very Small; and in between, the World of Life. Though my own training is in physics, I will spend a lot of time on the third part; the reasons will emerge later. I want you to get some feeling for the scales of length and time in these different realms, to appreciate the vastness of the macrocosmos and equally of the microcosmos, and then of life. I will then go back a little bit in time and recall some episodes from the history of science, bringing out its human face. We will see some of the philosophical and social repercussions of science at the end of the 18th century, then go on to progress made in different directions during the 19th. That will then bring us to the revolutionary advances of the present soon-to-end century.

At this point and against this background, I will turn to an examination of ourselves and 'our condition'. I wish to say something about science as an organised collective human activity; then view ourselves against the canvas of science, and lastly against the vast canvas of nature. It is important to see where we are led if we take the message of science seriously to heart.

The World of the Very Large

Table 1 gives you a very condensed survey of the World of the Very Large. We begin with the familiar earth-moon-sun system, and work our way steadily outwards. Here we are introduced to ever increasing scales of length and time (All figures in the various Tables are approximate). I have given distances both in terms of meters, roughly our size, and also equivalently in terms of light travel times. As we progress through the solar system, the stars and the Milky Way galaxy, clusters and superclusters of galaxies and finally reach the limits of the observable universe, we pass through some 27 orders of magnitude – the universe is 10^{27} times as large as we are, that is its immensity. Light takes about 8 minutes to reach us from the sun, but some 11 hours to go across the solar system. From one star to another one nearby it takes a few years; our nearest star after the sun is Alpha Centauri, about 4 light years away. Our galaxy – the Milky Way – contains some 10^{11} stars, and is about 100,000 light years across, a slowly rotating disc. Where in it are we located? About three quarters of the way out from the centre, hurtling along at 250 km per second.

Our galaxy and Andromeda are the two big ones in a local group of 30 galaxies; from one to the other light takes two million years to cross. Galaxies are grouped together into clusters and superclusters and so on to the entire universe. The universe contains about as many galaxies as each galaxy contains stars, so our glorious sun is but one among 10^{22} suns! The universe is about 15 billion years old, while the solar system – our address – is about 4.5 billion years old. And it takes light 10 billion years to go across the universe.

Table 1. World of the very large.

by = billion years = 10^9 years; 1 ly = 1 light year = 10^{16} m

Age of the Universe ~ 15 by; age of sun and planets ~ 4.5 by ~ (1/3 to 1/4) × age of universe

Object/distance	**Length in meters**	**Length in ly/ light travel time**
Earth radius	6.4×10^6	0.02 secs
Earth to moon	3.8×10^8	1.3 secs
Earth to sun	1.5×10^{11}	8.3 mins
Speed of earth around sun ~30 km/sec		
Sun radius (typical star)	7×10^8	2.3 secs
Sun to Pluto (solar system size)	6×10^{12}	5.6 hrs
Distance between nearby stars	few $\times 10^{16}$	few ly ~ few × 10^3 × size of solar system
No. of stars in typical galaxy ~ 10^{11} Mass of typical galaxy ~ $10^{11} \times M_{sun}$		
Diameter of Milky Way (typical galaxy)	8×10^{20} (~10^{21})	8×10^4 ly (~10^5 ly)
Thickness of Milky Way	6×10^{19}	6×10^3 ly
Diameter of spherical halo	10^{21}	10^5 ly
Solar system in Milky Way ~ 3×10^4 ly from centre, above galactic plane ~3/4 of the way out		
Speed of solar system around galactic centre ~250 km/sec		
Milky Way to Andromeda	2×10^{22}	2×10^6 ly ~20 × diameter of galaxy
Distance between nearby galaxies	4×10^{22}	4×10^6 ly
Supercluster ~ 10^5 galaxies; No. of superclusters ~ 10^6		
Radius of supercluster	10^{24}	10^8 ly ~1000 × Diameter of galaxy
Distance between nearby Superclusters	10^{24}	10^8 ly
No. of galaxies in universe ~ 10^{11}		
Radius of universe	10^{26}	10^{10} ly

Staggering as these magnitudes are, the point to emphasize is that the universe is lawful and understandable all the way. We are able to observe, analyse and theorise about the life histories of stars, the formation of galaxies, and the structure and evolution of the entire universe. Many problems remain at every stage, but we have the key concepts and methods and the power to create new ones, to comprehend it all. The universe is very largely empty space, save for electromagnetic radiation and neutrinos. At the level of stars the major physical forces at play are nuclear, electromagnetic, weak and gravitational forces; beyond that, at the galactic and higher levels, it is gravity all the way that controls everything.

In passing I might mention that the sun, about 4.5 billion years old, has another 6 billion years life left. Then it will expand, become a red giant, reach upto Mars and heat up the earth till lead melts and the oceans boil. By then life as we presently know it will disappear, at least from the solar system. The reassuring thing is that we still have 6 billion years to go.

The World of the Very Small

Now from this World of the Very Large let us swing all the way to the World of the Very Small, in *Table* 2. As mentioned earlier, the universe is practically matter-free; what matter there exists is made up of protons, neutrons and electrons. These are its normal constituents. The number of distinct chemical elements is about one hundred; and in mass they range from the hydrogen atom at one proton mass to the atoms of lead, uranium and the like at about 250 proton masses. Sizes in this realm are conveniently expressed in terms of the Angstrom, one Å being 10^{-8} cm. Molecules made up of a few atoms have sizes in the range of a few Å, may be 2 or 3 upto 6 or 8 Å. Individual atoms range in size from 1/2 Å for hydrogen to again 2 Å or 3 Å at the heavy end. Chemistry deals with atoms and molecules, and the dominating force there is electromagnetism. Looking now at the interior of the atom, again it is mostly empty space. The nucleus at the heart of the atom is a few fermis in diameter, one fermi being 10^{-5} Å = 10^{-13} cm. Practically all the atom's mass is in the nucleus, but the atom is 100,000 times as large as the nucleus! Far from the nucleus, the electrons roam around at the atom's periphery; they are the principal players in chemistry. Electrons are point like down to 10^{-16} cm i.e. a thousandth of a fermi. Within the nucleus all the forces – strong, electromagnetic and weak – have roles to play; what may be ignored in chemistry downwards is gravity. For all phenomena in the microscopic world and also involving radiation the language we need to use is the language of quantum mechanics. The most accurate theory in science, quantum electrodynamics or QED, belongs here. Beyond the electron, today we speak of quarks and leptons as the fundamental building blocks of matter. And bold theorists dream of phenomena at the Planck scale, lengths of order 10^{-33} cm, twenty orders of magnitude smaller than the nucleus.

Table 2. World of the very small

1 Angstrom = 1Å = 10^{-8} cm,   1 fermi = 1 fm = 10^{-13} cm.

Universe mostly matter-free, only radiation and neutrinos. Normal matter made up of protons, neutrons, electrons. Number of chemical elements ~100

Range of sizes: hydrogen ~0.5 Å ..... uranium, lead ~2 to 3Å

Range of masses: hydrogen ~one proton mass ..... heaviest elements ~250 proton masses

Molecules of a few atoms: $C0_2$, NH_3 ~2 to 3 Å .... 10 atoms ~ 5 to 8 Å

Chemistry: world of atoms and molecules: main force electro magnetism

Inside the atom proton ~ 1`fm .... Heavy nuclei ~5 to 6 fm

Nuclear size/atomic size ~ 10^{-5}

Electron size < 10^{-16} cm = 10^{-3} fm

In nucleus: strong, electromagnetic, weak forces.

Basic building blocks of matter: quarks and leptons

Microscopic world: language of physics = Quantum mechanics

Planck length ~10^{-33} cm

All of this again is accessible to human understanding, and new laws of nature couched in the language of quantum mechanics hold sway. The presently accessible physico-chemical world thus spans some 44 orders of magnitude, and it is comprehensible all the way.

The World of Life

Let us now finally look at the World of Life, and our own place in it. Here it becomes necessary to focus successively on several different aspects, each important for our story. To begin with, we must realise that life differs from physics and chemistry in certain ways. The laws of physics and chemistry are the same always and everywhere in the universe, they have a character of universality. But – as far as we know – life has occurred and evolved just once, and here on planet earth. Therefore its study has a historical and teleological character, a subtle illusion of moving towards a goal, in ways which are inappropriate in physics and chemistry. Keeping these in mind, let me first briefly review the evolution of life, sketched in *Table* 3. As we saw, the earth is some 4½ billion years old,

Table 3. The Evolution of Life

(by = billion years, my = million years)

Emergence of	**How long ago**
Earth	4.5 by
Nucleotides, aminoacids	4.0 by
Earliest life forms	3.8 by
Bacteria	3.1 by
Cell + Structures inside	2 to 3 by
Protists	1.2 by
Fish	500 my
Mammals	200 my
Primates (origin of monkeys, humanoids)	80 to 90 my
Monkeys	50 my
Apes (origin of chimps, gorillas, orangutans, hominids)	35 my
Hominids	3 to 5 my

Bacteria ——— 1by —> cell + nucleus ————————— 1 by—>
Multicellular organisms, —— 1 by —> mammals
Nerves, CNS

and it is interesting that life already appeared 700 million years later. In this context, that is quite fast; life has been around for one quarter of the age of the universe itself ! Now we go down the different levels of steadily increasing sophistication and complexity of life forms – bacteria appeared 3.1 billion years ago, the cell and its structures 'soon after'. The fishes are 500 million years old, mammals 200 million years old. And so we move on through primates, monkeys and apes to our own ancestors – the hominids – who appeared on the scene a mere 3 to 5 million years ago.

To keep things in focus let me remark: Evolution from bacteria to the primitive cell took one billion years; from there to multicellular organisms, the development of nerve pathways and a central nervous system (CNS) was another billion years; and the next major step, the appearance of mammals, took again a billion years.

It is interesting to trace the points of divergence in the evolutionary tree leading ultimately to ourselves, starting from mammals 200 million years ago; I give this in *Table* 4. Mammals themselves evolved out of reptiles. Then the primates took off 70 million years ago. The two groups of monkeys branched off next, one after the other, around 45 million years ago. The next stage was the appearance of the apes some 30 million years ago. Finally from out of these came the hominids just 5 million years ago. And we can date the advent

Table 4. Points of divergence in recent evolution

Event	How long ago
Reptiles to mammals	200 my
Arboreal mammals to primates	70 my
Primates to New World monkeys	> 45 my
Primates to Old World monkeys	45 my
Old World monkeys to Apes	30 my
Chimps, gorillas to hominids	5 my
Erect stature in hominids	since 3 my

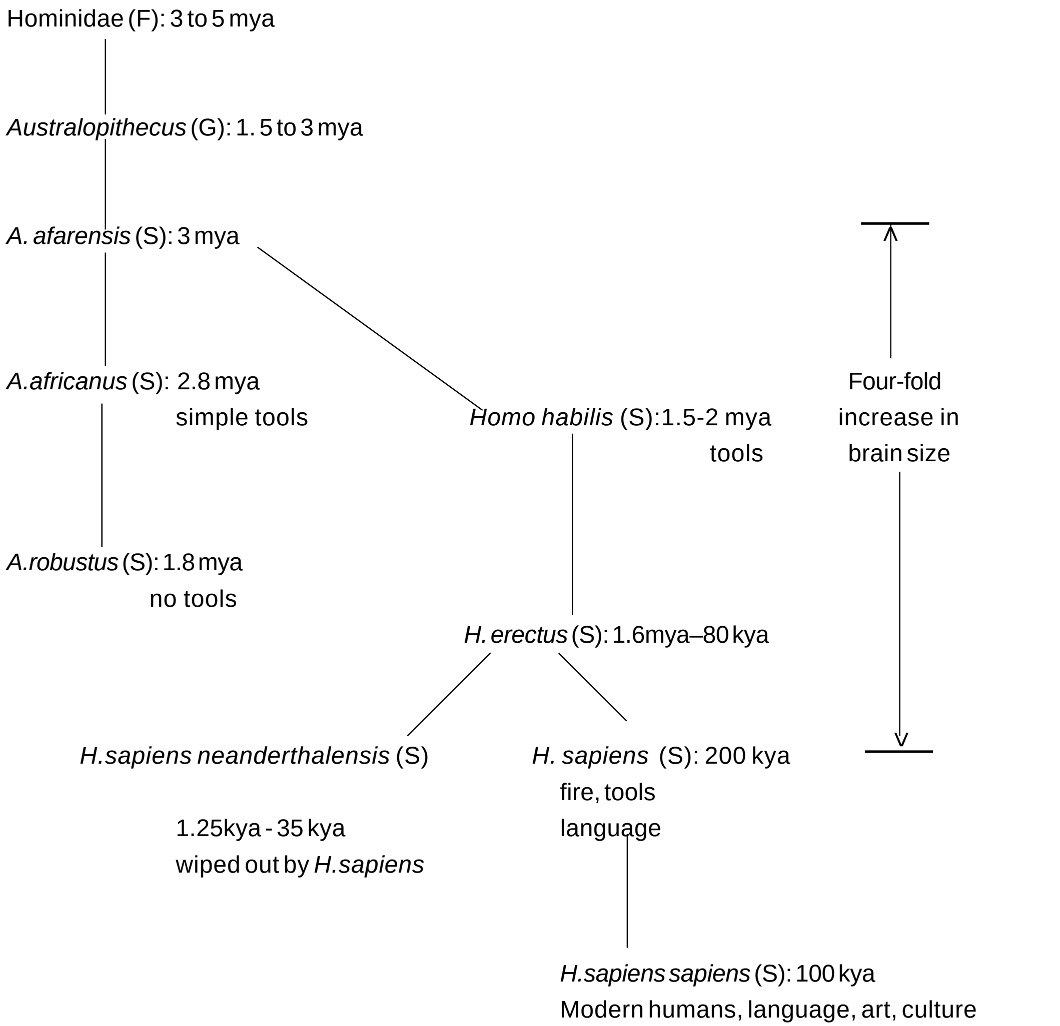
of erect stature, leaving two limbs free to do other things, to about 3 million years ago.

I am giving you a series of snapshots of shorter and shorter time spans. We look next, in *Table* 5, at just the Hominid line over the past 5 million years, ending with our immediate ancestors the *Homo sapiens sapiens*, indeed, ourselves. This is presented in the form of an (inverted) tree with branching off points. In biological terms the hominidae form a Family and they began some 3 to 5 millions years ago. Already they were upright walkers. They gave rise and place to the Genus Australopithecus (genus is a smaller unit than family) who flourished 1½ to 3 million years ago. Next, the species *Australopithecus afarensis* (species is a smaller unit than genus) to whom 'Lucy' belonged; that was around 3.8 million years ago (You see that these figures are very approximate!). Then there was a divergence: the species *Australopithecus africanus* followed by the species *Australopithecus robustus* on one branch, both now long extinct. The other branch, via *Homo habilis* and then *Homo erectus*, split again into two lines: the species of the Neanderthalers and the species *Homo sapiens*, 'just' around 200,000 years back. And no more than 100,000 years ago came our own modern human species, *Homo sapiens sapiens*. The Neanderthals were wiped out by 'us' just 30000 to 40000 years ago. Between *Australopithecus* and *Homo sapiens*, in the time span from 3 million years to 200000 years ago, the size of the brain increased by a factor of four. We have probably had the language faculty since almost 200000 years. And with the arrival of *Homo sapiens sapiens* as recently as 100000 years ago we have the emergence of language, art and culture – cultural evolution speeding up and overtaking genetic evolution.

At this point you may wonder – why is he telling us all this? For good reasons – it is fascinating to trace our origins; I later want to speak about 'the human condition' against this background; and remember that in many places in the most developed country in the world it is forbidden to teach such things!

Table 5. The Hominid line (F = family, G = genus, S =species)

mya = million years ago, kya = thousand years ago



We have been talking of vast expanses of time – billions and millions of years – and it is not easy to grasp these enormities. Just as a help to the imagination, I show you in *Table* 6 a few events since the arrival of *Homo sapiens sapiens* just 100000 years back, in two ways – in terms of number of years elapsed, and in terms of human generations elapsed. This may help to make things more tangible at least at that scale. As a species we are a modest 5000 generations old. Agriculture and civilizations arose 500 generations ago, and the earliest

Table 6. A few recent events

Event	How long ago (years)	No. of generations ago
Homo sapiens sapiens, Language faculty	100,000	5000
Agriculture, civilizations	10,000	500
Early Pharaohs	5,000	250
Pyramids at Giza	4,500	225
Queen Nefertiti, King Tut	3,350	168
Buddha	2,500	125
Christ	2,000	100
Modern science (Galileo, Newton)	350	18

Pharaohs ruled 250 generations ago. They built the Pyramids at Giza some 225 generations in the past. The Miss Universe of those days, Queen Nefertiti, and her nephew King Tut, ruled nearly 170 generations ago. The Buddha and Christ date back respectively 125 and 100 generations; and modern science is a mere 18 human generations old.

Continuing our journey through the World of Life, let us now briefly switch from evolutionary history to the mechanics of life, how it is organized and what makes for its unity. A convenient starting point is the cell (which you recall appeared in primitive form around 3 billion years ago); from here we can either go upwards towards the organism, or downwards into its microscopic constituents. From *Table* 7 you see that a typical cell is about 10^{-4} cm in diameter, and has a mass of about 5×10^{-12} kg, which comes to some 10^{15} proton masses. An adult human has about 10^{14} cells in all; this number can be grasped as being the result of close to 50 cell divisions or cell generations, each division doubling the number of cells. The cell is a most incredibly efficient chemical factory. And some of the most fascinating problems in biology involve development, the route from the single fertilized egg to the adult organism.

Table 7. Cell and upwards

Size of a typical cell $\sim 10^{-6}$ m = 10^{-4} cm
Mass of a typical cell ~ 5×10^{-12} kg $\sim 10^{15}$ proton masses
No. of cells in adult human $\sim 10^{14}$ = result of ~50 cell divisions
Single fertilized egg —> adult organism: domain of developmental biology

Table 8. The cell and some contents

DNA = basic genetic material constituting chromosomes
= double stranded helix,
each strand = string of nucleotides

Alphabet of DNA has 4 letters : A, T, G, C; pairing rule across strands: A $\leftrightarrow$ T , G $\leftrightarrow$ C

Word of 3 letters (3 nucleotides) $\rightarrow$ code for one amino acid

No. of amino acids = 20

Mass of amino acid ~100 proton masses

100 to 10000 (average 300) amino acids in sequence = one protein

Mass of protein ~10^4 to 10^6 proton masses

Bacterium ~3000 distinct proteins

Humans ~10^5 distinct proteins

Human genome ~3.5 million base pairs

Some of the major contents of the cell, the players in the game of life, are shown in *Table* 8. From the bottom up: DNA – the basic genetic material making up the chromosomes – is a double stranded helix, built on a repertoire of 4 letters. The alphabet of life consists of the 4 nucleotides A, T, G and C as they are called, with the pairing rule in the helix that A and T always face each other, and similarly for G and C. A word of three letters – a string of 3 nucleotides – represents or codes for one amino acid, of which there are 20; and anywhere from 100 to 10000 amino acids (300 on the average) strung together form a protein. A gene is a stretch of DNA coding for one protein, hence on average it is some 1000 nucleotides in length. Thus we have the progression nucleotides $\rightarrow$ genes $\rightarrow$ proteins built up of some 300 amino acids each. In terms of proton masses amino acids have on average the mass of a hundred protons, while a protein has a mass of 10^4 to 10^6 protons. While a simple bacterium contains some 3000 distinct proteins, we humans have about 100,000 of them, and our genome – entire gene content – is about 3½ million base pairs or nucleotides long. All this is accompanied by an intricate machinery for replication, translation, transcription, transport, catalysis and manufacture and synthesis and the like, involving many other actors like RNA, etc. All are results of billions of years of slow evolution. And essentially these structures pervade *all* of life – plants, insects, animals, us.. without exception. That is the meaning of the unity of life.

I have shown you glimpses of all the three Worlds – the Very Large, the Very Small, and Life – all the results of 3½ centuries of scientific effort. Now it is time to look a little bit at the history of that effort itself. And to answer a natural worry in your minds: after so much information, where is the knowledge; and further, where is the wisdom? Patience!

The Early Impact of Science

From the foundations laid by Galileo and Newton, right through to the end of the 18th century, physical science scored triumph after triumph in explaining natural phenomena. These were in celestial mechanics or astronomy, in mechanics, in fluid dynamics, and towards the end in electricity and magnetism as well. The approach based on Galilean–Newtonian principles was so successful that in the late 1700's it led to three very interesting claims or developments which I would now like to mention. One was the statement of the mathematican-physicist Pierre Simon Laplace that the entire universe was like a clockwork mechanism – to a supremely intelligent mind with all-seeing eyes and unlimited calculating powers, on the basis of Newton's equations and knowledge of all the forces in nature, the present would completely determine the future, and for that matter the past as well. This was Laplace's doctrine of complete determinism. Another was the impact on the thinkers of the Enlightenment – the success of natural science led them to claim that human societies too could be perfectly organized and social progress was inevitable. In the words of the Marquis de Condorcet as paraphrased by Edward Wilson – "...culture is governed by laws as exact as those of physics. We need to only understand them ... to keep humanity on its predestined course to a more perfect social order ruled by science and secular philosophy. These laws ... can be adduced from a study of past history".

Today we can say that both these views were results of being blinded by the successes of science of that time, and of rash extrapolations both within science and outside it. Science is much more modest in its attitudes today – the physical universe is much too complex and rich for us to believe literally in Laplacian determinism; and as for society there are far too many historical and cultural factors and variations to naively believe in the inevitable universal progress of social institutions.

In some ways the most profound of the effects of science on thinking at that time is the third point to which I now turn. The great Immanuel Kant, the philosopher of the Enlightenment, set out to explain why Galilean–Newtonian physics was so successful. At that time there were two contrasting philosophies concerning our knowledge of nature – the rationalist which believed that nature was subordinate to and had to obey reason; and the empiricist which held that all knowledge had to come from experience. Kant tried to combine both in a new way and said that while knowledge is certainly drawn from experience, we already possess at birth certain “synthetic a priori categories of thought” that constrain the behaviour of nature. In other words our understanding of nature is in terms of certain principles which are inborn in us prior to experience of nature. In his view, some of the empirical facts about nature – such as the properties of space and time, the law of cause and effect, simultaneity, the conservation of matter and in the end even some of Newton’s Laws – were not subject to verification or denial by experiment; they had necessarily to be true as they were the basis of all understanding of experience and could never be contradicted by it. Briefly put, we know certain things about the behaviour of nature even before we have experience of nature. So something was explained by saying that it was inevitable, it could never be otherwise. The question that arises for us today is: if we know something about the world even before we see it, what is the source of this knowledge?

I will tell you later about the resolution of this problem. But for the moment let me just remark that the Enlightenment program, especially in its social aspects, failed and led in the early 19th century to a romantic reaction in philosophy, in poetry and in the expression of our relation to nature. For Science however this was a good thing – it was essentially left alone to make progress by itself based on experiment and mathematical analysis. In all fields there was great progress and I can mention only a few highlights.

Science in the 19th and 20th Centuries

In physics, based on landmark experiments, the concept of the electromagnetic field was created by Michael Faraday. In Maxwell’s hands, this led later to the unification of electricity, magnetism and optics; light was seen to be an electromagnetic wave. The science of thermodynamics grew, while celestial mechanics continued to prosper. Chemistry progressed as a combination of descriptive and quantitative aspects, and the pattern of the elements as systematised by Mendeleev’s table was established. In the life sciences the Darwinian theory of evolution by natural selection was propounded, though at that time the material underpinnings of heredity and its variation and transmission were not yet known. The basic principles of heredity were discovered by Gregor Mendel, lay forgotten, and had to be rediscovered in the beginning of this century. At least as far as physics was concerned, the basic view of natural phenomena was a mechanical one – in fact for a long time Maxwell tried to interpret electric and magnetic fields in terms of gears and wheels, not as basic irreducible entities in their own right.

The physics of this century has shown nature to be far more subtle, abstract and rich than was ever previously imagined. This has been so with all the three major advances – special relativity, general relativity and then quantum mechanics. Each of these has deep and characteristic mathematical structures, aesthetic features leading to unparalleled beauty. The role of mathematics in understanding the physical universe has grown beyond any reasonable earlier expectations. Eugene Wigner spoke of "The Unreasonable Effectiveness of Mathematics in the Natural Sciences"; and Paul Dirac wrote of "....some mathematical quality in nature, a quality which the casual observer of nature would not suspect, but which nevertheless plays an important role in nature's scheme".

Today we know that it is through quantum mechanics that we reach true understanding and explanation in chemistry. In a sense, chemistry and the Mendeleev table before quantum mechanics are like Kepler's Laws before Newton's Laws of Motion and of universal gravitation. The parallel in the life sciences would be the efforts of Carolus Linnaeus (at least as far as natural history is concerned) before the Darwinian revolution. In turn chemistry and biochemistry have provided the foundations for understanding life processes, and through them we see disclosed the amazing unity of life in all its forms. If we look at physics, chemistry and the life sciences in that sequence, we see their relationships in a new light: they are mutually consistent, each dovetails into the next and provides its foundations, but each also preserves its autonomy too and works with concepts suited to its domain. It is just too hard for us to trace all the phenomena of chemistry back to the starting principles of physics, and similarly from life to chemistry. It is all a fine combination of hierarchical interdependence, consistency and autonomy because what is calculable in principle is not so easy in practice.

Ourselves Viewed Against Science

Time now to view ourselves against science. It is important to realise that science is an organised human activity, a collective process; and its results are part of our cultural heritage. In Heisenberg's words: "Nature is prior to man, and man is prior to natural science". For all its shortcomings, and remembering that scientists are no angels, it is the one activity that has a built-in self-correcting mechanism and leads to dependable truth, a body of critically tested knowledge we can trust. It grows cumulatively, and while individuals make discoveries and contribute to the body of verified scientific knowledge, once discovered it becomes part of an objective whole, in a sense detached from the particular individual. There is no sense of value within scientific knowledge itself, no meaning to good or bad in a moral sense; though we do judge some discoveries as being deeper or more fundamental than others. This was very succinctly expressed by Bertrand Russell: "Science, by itself, cannot supply us with an ethic. It can show us how to achieve a given end, and it may show us that some ends cannot be achieved". Perhaps most important, while science is a never-ending exploration, is the lesson that nature is understandable, and at no stage is there reason for fear of as yet unanswered questions, no need to look for makeshift pseudo explanations.

We have seen that we are the products of a very long evolutionary process in which over the past 100,000 years the genetic component has been dominated by the cultural component. We come equipped with certain senses, but they are limited as they have been fashioned by evolution to function within a certain biological niche. It is through science that we transcend these limitations and come to know of the great range and variety of natural phenomena inaccessible to our unaided senses. As science advances, previously understood phenomena become instruments for further exploration into nature. In the words of Julian Schwinger: “It is remarkable how nature aids mankind’s groping towards an understanding of the universe. As we raise the level of our scientific skills and sharpen our artificial senses, fascinating new phenomena continue to appear, testing and challenging our growing comprehension of nature’s grand design”. The evolutionary process is also a learning process – slow progress via natural selection retains and perfects those capacities in us that are best able to recognize the aspects of the world which are important for life. Thus the species ‘learns’ as it evolves; but to the individual member of the species those evolved abilities appear inborn, given right at the start at birth and perfectly suited to handle later experience. This is the explanation given by Konrad Lorenz to the origin of the Kantian a priori. Both experience and learning operate at two levels – at the species level as it evolves, and also between birth and death in the life span of each individual. A fascinating ‘play within a play’ situation, an insight based on Darwinian evolution not available in Kant’s time. As Delbrück expressed it, “What is a priori for individuals is a posteriori for the species”.

The brain is the most complex form of organised matter known to us anywhere in the universe. It too has been through a very long evolutionary process. In *Table* 9, I present some salient features of this past. The evolution of the brain is a 400 million year old saga, passing from fish through frog through reptiles to mammals, and then on to primates to the hominid line. While the human brain reached its present condition some 100,000

Table 9. Evolution of the brain.

History of brain = 400 million years saga: fish $\rightarrow$ frog $\rightarrow$ reptiles $\rightarrow$ mammals $\rightarrow$ primates $\rightarrow$ hominid line

3 million years ago to 200000 years ago: 4-fold increase in brain size, mainly neo cortex $\rightarrow$ higher functions, language, culture.

Ancient instinct much older than reason
Ethical sense much older than religion

Table 10. Complexity of human brain

Brain ~10^{11} nerve cells, each 10^{-4} cm diameter, each connected to 100-1000 others.

Total number of connections ~ 10^{14}
Volume ~ 1.5×10^3 cc, mass ~ 1.3 kg
Brain structure controlled by at least 3200 genes (out of 100000)
Highly folded cortex ~ 75 cm $\times$ 75 cm square sheet
Language faculty ~100000 years old; ~10000 languages in all
Capacity to simulate experience, then choose action.
Religious feelings – genetic roots
Preconscious processing – sensory inputs, decisions, illusion of free will

years ago when *Homo sapiens sapiens* appeared, it contains relics of this long evolutionary growth. Many patterns or predispositions for thought and action are of genetic origin, howsoever we may wish otherwise. In a real sense we are on a genetic leash, we are not as free as we think or like to imagine we are. Instinct is much older than reason; and even while we are the only species to deliberately harm and kill one another, the ethical sense and even altruism are much older than religion.

As for the complexity of the human brain, the bare figures in *Table* 10 speak for themselves. The quadrupling of brain size over the hominid line from three million years ago to 200,000 years ago, mainly the neocortex, brought many uniquely new capacities. These include the language faculty and the capacity for simulation of experience – the power to imagine several events and courses of action, to weigh them and then to choose from among them. The language faculty, unique to us, is some 100,000 years old, and is the key to cultural evolution. It is genetically wired in; we all know how much easier it is for young children to pick up several languages simultaneously than for an adult to pick up even one. And there have been some 10,000 languages in all. Even the tendency towards religious feelings seems to have genetic roots. Damage to particular regions of the brain is known to lead to hyperreligious feelings, and it has been estimated that we have had 100,000 religions already. Now it is time to go beyond traditional religious forms, but we all know how difficult that is.

What next about free will and the nature of the mind? Here we learn that a great deal of preconscious processing and activity goes on all the time in the brain; this is particularly well known in the handling of sensory inputs such as vision. What emerges into the conscious realm is the end product of all this prior activity. With free will too it is similar. Patterns of decisions and choices among alternatives are genetically influenced in the form of predispositions, they follow epigenetic rules; and only at a late stage do they surface into consciousness and create the illusory feeling of having consciously made a free choice. But even as an illusion this feeling is important for survival! As for the mind, the evolutionist tells us that it has developed to help with biological survival, not to understand itself; and in Delbrück's words: "In the context of evolution, the mind of the adult human, the object of so many centuries of philosophical studies, ceases to be a mysterious phenomenon, a thing unto itself. Rather, mind is seen to be an adaptive response to selective pressures, just as is nearly everything else in the living world".

Ourselves Viewed Against Nature

Let me draw to the end and come to the question – how do we view ourselves against nature? In more than one way we see that we are very lonely. We have seen the vastness of nature and – starting with the Copernican revolution – it is difficult indeed to believe that we are central to nature. Feynman said it beautifully: " .... I can't believe these special stories that have been made up about our relationship to the universe at large because they seem to be too simple, too connected, too local, too provincial. The earth, he came to the earth, one of the aspects of God came to the earth, mind you, ... and look at what's out there. How can He... it isn't in proportion".

Then there are yet other ways in which loneliness – as a species and as individuals – bears down upon us. The emergence of life on earth is the result of a chance occurrence; before the event, the probability of its happening was essentially zero. And in Monod's powerful phrase taken from Democritus, the processes of life combine 'Chance and Necessity' in a profound way. The genetic roulette upon which natural selection plays is a roulette of pure blind chance, with no direction or purpose. It is the intensely conservative nature of the replication processes of life – the preservation of genetic structure – which allows for testing competing alternatives in the biological world and weeding out the less adapted. This too speaks of loneliness. And at the level of the individual, there are deep unbridgeable limits to communication with other individuals. We believe we all 'see' the same colours, 'hear' the same sounds, and think similar thoughts; but never will we ever know that this is so. For in nature itself there is neither 'colour' nor 'sound'. In Erwin Schrödinger's eloquent words: "... the scientific world view contains of itself no ethical values, no aesthetical values, not a word about our own ultimate scope or destination, and no God, if you please ... Science cannot tell us a word about why music delights us, of why and how an old song can move us to tears". It is our belief in our common biological heritage that encourages us to think we perceive and react to nature in the same ways, but of this there can be no direct confirmation. In another context R K Narayan wrote: "A profound and unmitigated loneliness is the only truth of life".

Science has shown to us our location in nature, and also the fact of our loneliness – as a species, as individuals. There are many different ways in which one may react to this. My own is along these lines.

To come to terms with individual loneliness is very difficult, it can be frightening. To realise and accept that there is no one 'out there' specially taking care of us, that the world was not created for us or with us in mind, *that* needs extraordinary courage. And yet we have evolved as social beings, we crave companionship – may be a subconscious reaction to realising the limits of communication? Einstein once said that "Man is, at one and the same time, a solitary being and a social being". All that can sustain us then are knowledge, and compassionate love. Knowledge that there is a 'central order' in nature accessible to our understanding, even if it is insensitive to values, and which we can approach with wonder rather than fear. And compassion for the other whose loneliness is as profound as one's own. From these alone can spring ethical principles, aesthetic values and the pursuit of quality in all striving – all of which are vital and real to us as a species, even if absent in Nature – and all are ultimately attempts to bridge the unbridgeable.

Suggestions for Further Reading

[1] Max Delbruck, *Mind from Matter? An Essay on Evolutionary Epistemology*, Blackwell Scientific Publications, Inc., 1986.

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[3] E P Wigner, *Symmetries and Reflections*, Ox Bow Press, Woodbridge, Connecticut, 1979.

[4] W Heisenberg, *Physics and Beyond-Encounters and Conversations*, George Allen and Unwin Ltd., 1971, (especially Ch. 10).

[5] E Schrödinger, *My View of the World*, Ox Bow Press, Woodbridge, Connecticut , 1983, *Mind and Matter*, Canto Series, Cambridge University Press, 1992; *Science and Humanism*, Canto Series, Cambridge University Press, 1996.

[6] R P Feynman, *The Pleasure of Finding Things Out*, WGBH Transcripts, 125 Western Avenue, Boston, Mass 02134, 1983.

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