Chapter 0: introduction

background reading

Baggott, J. (2015), *Origins: the scientific story of creation*, Oxford University Press.

Bryson, B. (2003), *A short History of Nearly Everything*, Doubleday, London.

Dawkins, R. (2005), *The Ancestor's Tale: a pilgrimage to the dawn of life*, Phoenix, London.

Gribbin, J. (2008), *The Universe: a biography*, Penguin, London.

Morowitz, H. (2002), *The Emergence of Everything: how the world became complex*, Oxford University Press.

notes

Scientific books and research papers often have many authors, and some authors have many publications to their name. To keep references both simple and precise, I give every reference in the same format, as <first author> <year>:<page number>. The year is followed by a letter, such as a, b, c, if I refer to more than one publication from that author in that year. Page references are by far the most common and these are referred to just by number, while chapters, sections, and tables are individually mentioned.

Constructive comments are welcome.

0.1 what this book is about

"**We now have a well-established scientific description**", see Atkins 2018, Baggott 2015, Bryson 2003, Chaisson 2005, Christian 2018, Dawkins 2005, and Jastrow 2008.

" **… the universe as a hierarchy of material communities …**", also see the note at the start of chapter 9. The view of the universe as a hierarchy of some kind is quite common, but as far as I know, no one has proposed a self-consistent hierarchy of interacting *communities* of things, from the simplest physical entities to human society.

Joseph Needham has come close. He perceived "*the existence of levels of organisation in the universe, successive forms of order in a scale of complexity and organisation*", which he called a "*scala naturae*" (Needham 1986:234 and 1968:xii). Needham saw this *scala naturae* as a sequence of "*spatial envelopes – the electron in the atom, the atom in the molecule, the molecule … in the cell, the cell in the organ, the organ in the body, the body in the herd or the tribe or community, and perhaps the community in the world cooperative commonwealth yet to come*" (Needham 1968:xii).

"*The fundamental thread that seems to run through the history of our world is a continuous rise in the level of organisation*" (Needham 1986:185). So, "*ultimate particles, the proton, electron etc. build up atoms, atoms build molecules, molecules … are organised into the living cell … cells form organs and tissues, the latter combine into the functioning living body, and the bodies of animals, especially men, form social communities. As the central nervous system becomes more complex so mental phenomena emerge, until the elaborate psychological life of man is attained. There is a sense in which minds include and envelop bodies, for the boundaries of thought are far wider than those of what the special senses can record, and minds interpenetrate as bodies cannot*" (Needham 1986:184).

The universe's evolution is a cumulative succession of aggregations, so it "*achieves its values by reason of its co-ordination into societies of societies, and societies of societies of societies. Thus an army is a society of regiments, and regiments are societies of men, and men are societies of cells … and cells are societies of smaller physical entities such as protons and so on*" (Whitehead, quoted in Needham 1986:193).

More recently, Peter Atkins has written "*I am taking the view that the ultimate fabric* [of the universe] *must be of extreme simplicity, and that its perceived complexity and richness must be a result of primitive things grouping together into gangs*" (Atkins 1992:17).

Many scientists, from a range of disciplines, have commented on the natural hierarchy of physical systems and their levels of organisation, for example, Needham 1968:chapter 3, Bronowski 1977:chapter 13, Koestler 1979:chapter 1, Needham 1986:184, 193 and 234, Reeves 1991, Feynman 1992:124, Calvin 1997:34, Holland 2000:chapter 1, Morowitz 2002, and Laughlin 2006:chapter 1. Each level has its own principles and laws, and Laughlin and Feynman write of hierarchies of laws of behaviour.

Some writers have proposed a series of stages, or transitions in the universe's evolution, for example, Smith 2000, Chaisson 2005, and Christian 2018.

Smith 2000 identifies major transitions in evolution, based on the idea that "*evolution depends on changes in the information that is passed between generations*" (2000:preface). He proposes 8 levels, starting with the first replicating molecules and ending with the origin of language, so there are no inorganic systems (Smith 2000:16).

Reeves sees language as having a hierarchical structure, with letters, words, sentences, paragraphs, and chapters at successively higher levels (Reeves 1991:chapter 2). "*The same structural pattern is repeated at every level: The units are composed of elements from the lower level, and they themselves will combine to compose the units of the next higher level*" (Reeves 1991:39). Reeves sees nature as being structured like a language, so he puts quarks, nucleons (protons and neutrons), atoms, molecules, cells, and organisms at successive levels in a pyramid of complexity. Just as letters combine to form words, atoms are the "letters" that combine to make molecules. Reeves bases his scheme on a linguistic analogy, doesn't go beyond organisms, and doesn't include nuclides. He notes that as you go up the pyramid, the binding energy decreases, and the systems become more complex (Reeves 1991: 46 and 83).

Reeves notes that the pyramid shape reflects the fraction of matter at each level (Reeves 1991:51). So, few nucleons are in atomic nuclei, few atoms are in molecules of any size, few molecules are in biological cells, and very few cells are in complex organisms. Conversely, the increasing number of species at successive levels is represented by an inverted pyramid. So, there are only two types of nucleon (proton and neutron), and these are the basis for about 100 different atomic elements, which form millions of different molecules, and billions of different living organisms. All protons and neutrons are identical, as are the isotopes of each element, and the molecules of the same compound, but every living organism is unique. So, as we ascend the pyramid of complexity, "*the more ways we find to differentiate between forms sharing the same level*" (Reeves 1991:51).

Christian sees eight thresholds in the evolution of the universe, with the first being the Big Bang, and the last being the fossil fuels revolution (Christian 2018:13).

Chaisson sees seven epochs in the universe's evolution – particle, galactic, stellar, planetary, chemical, biological, and cultural (Chaisson 2005).

0.2 the universal hierarchy

0.2.1 taking things apart

"**Each of these molecules**", Atkins 1992:11.

"**We can't take things apart**", quarks are not the only fundamental particles, but they are the last things we find when we take matter apart – they are the last Russian doll in the series.

"***substance without inside***", Atkins 1992:15.

"***mass-energy***", Hogan 1998:chapter 3 gives a concise and accessible explanation of "mass-energy".

"***frozen energy***", Close 2004a:68.

"***a material particle***", Ford 1991:27.

0.2.2 the universe evolves by forming communities of things

"**When we follow the universe's evolution**", see, for example, Weinberg 1993a, Hogan 1998, Freedman 2002, and Gribbin 2008 on the creation of the inanimate universe; and see Fortey 1997, Margulis 1997, Purves 1998, Morowitz 2002, Dawkins 2005, Rutherford 2014, and Gee 2021 on the origin and evolution of living things.

A growing number of authors are providing comprehensive accounts of the evolution of the universe; see, for example, Calvin 1986, Delsemme 1998, Smith 2000, Morowitz 2002, Bryson 2003, Chaisson 2005, Jastrow 2008, Baggott 2015, and Christian 2018.

"**A communal cluster of protons and neutrons**", a nucleus is the central part of an atom, while a nuclide is a specific nucleus, with a particular number of protons and neutrons (Gribbin 1998). So, nuclide is to nucleus as oak is to tree, or braeburn is to apple.

"**A nuclide becomes the centre**", quarks and electrons are both fundamental particles. Quarks spontaneously bind together to make protons and neutrons at Level 1. In contrast, electrons carry a negative electric charge, and so repel each other, and can only form communities around an attractive positive charge, which is the nuclide at Level 2.

"**Thus a select community of chemical reactions**", this is a "protein-centric" view that Gerrard has described as "*turning biochemistry inside out*" (Gerrard 2005).

"***local embodiment of a Cosmos***", Sagan 1981:345.

Figure 0.1 is based on Duff 1986:figure 1.1, Heyde 1998:figures 1.1 and 1.3, and Close 2007a:figure 1.2.

The universe as a whole is a nested hierarchy, within which are innumerable branched hierarchies. A nested hierarchy resembles the concentric layers of an onion, and is a "bottom-up" hierarchy, in which each level is subsumed or contained by the next higher level, and the lower/inner levels sustain the higher/outer levels. A branched hierarchy is a "top-down" hierarchy, consistent with command and control from higher levels to lower levels. This is discussed in section 9.1.1. Koestler (1967:chapter 4 and 1979:chapter 1) discusses types of hierarchies.

Figure 0.1 summarises the nested hierarchy in the text, and one possible branched hierarchy in the images, which connect all eight levels of the universal hierarchy, from quark trios in Level 1 up to the neurally connected human society in Level 8. The inter-connected brains in **Level 8** can be regarded as one giant brain, for we all draw on the knowledge and expertise of others. The chimpanzee brain at **Level 7** is redrawn from https://commons.wikimedia.org/wiki/File:Human_and_chimp_brain.png. The fish was chosen as the organism at **Level 6** because it has a simple recognisable outline, within which the neuron can be placed. The cell at **Level 5** is a hand-drawn sketch of a typical rod-shaped bacterium, based on Campbell 2015:figure 7.5. The 3−D image of the molecule glycine at L**evel 4** is from ChemSpider, CSID:730, http://www.chemspider.com/Chemical-Structure.730.html (accessed 15:24, Jun 9, 2023). The "atom" shown at **Level 3** is the "Rutherford" atom (Carroll 2019:45), which is a misrepresentation, but one that is universally recognised. The nuclide at **Level 2** is the cluster of 6 protons and 6 neutrons that comprise the nucleus of carbon-12. A cluster of 2 *up* quarks and 1 *down* quark (*uud*) makes a proton, while the cluster *udd* makes a neutron (**Level 1**), and this distinction is shown in the figure.

"**Each level builds on the one below**", over 60 years ago, Herbert Simon presented a perceptive and accessible commentary on complex systems (Simon 1962). See also the note on section 9.3.

He remarks on the hierarchical structure of many physical systems, extending from atoms, through molecules to planets and galaxies, and of biological systems, extending from nucleus and mitochondria, through cells and tissues to organs (Simon 1962:469). Simon doesn't link the chemistry of molecules to the metabolism of the cell, and so the two hierarchies remain separate.

Simon shows, from simple principles, that simple systems will come together to evolve into a more complex system more readily if they can form a series of stable intermediate systems. In this case the final complex system will be hierarchic (Simon 1962:473). He concludes, "*On theoretical grounds we could expect complex systems to be hierarchies in a world in which complexity had to evolve from simplicity*" (Simon 1962:482).

0.2.3 right here, right now

0.3 the emergence of new properties and powers

"**We're familiar with the idea**", Dawkins 2005:7, and his book is a journey back to biological life's first molecular ancestors.

"**If we extend this idea**", Adrian Woolfson has had a similar idea – "*We all walk tall on the shoulders of an unbroken chain of ancestors and a string of historical events which date back fifteen billion years or so to the beginning of the universe*" (Woolfson 2000:109).

"**Every particle in our bodies**", so if you could have marked a handful of fundamental particles in the very early universe, and followed them as the universe evolved, then you would see them now in various places – in deep space, in stars, in planets and in ourselves. For example, see Krauss (2002:172) on the evolution of the oxygen atoms that have ended up on planet Earth, and Primo Levi (1986:224) on the possible experiences of a carbon atom.

The Big Bang is now generally accepted as the origin of the physical universe (Weinberg 1993a, Hogan 1998, Allday 2002, Gribbin 2008).

"**At each stage**", see Morowitz 2002:13, Feynman 1992:124 and Ellis 2006:80. The appearance of novelty has led to the common observation that an emergent whole is more than the sum of its parts (Holland 2000:14, Morowitz 2002:20).

John Barrow observes that "*As we bring simple things together, they produce aggregates that exhibit a wider diversity of behaviour than the sum of their parts. Thus qualitatively new phenomena appear as the level of complexity rises or the number of ingredients increases*" (Barrow 1992:140).

The philosopher Charles Broad created the term "emergent properties" in the early 1920s, for "*those properties that emerge at a certain level of complexity but do not exist at lower levels*" (Capra 2016:65).

Capra and Luisi explain that "*Emergence, in the most classic interpretation, means in fact the arising of novel properties in an ensemble, novel in the sense that they are not present in the constituent parts*" (Capra 2016:133).

They contrast the emergent and reductionist views of things: "*The difference between structure and properties is fundamental at this level: reductionism, then, is fine when it limits itself to structure and composition. Emergence assumes its real value at the level of properties, and its very notion is based on the proposition that the emergent* ***properties*** *cannot be reduced to the* ***properties of the parts****. This is a somewhat subtle point: on the one hand, we are saying that biological life is chemistry only; on the other hand, we also state that the arising of life as a* ***property*** *cannot be reduced to the properties of the single chemical components*" (Capra 2016:133).

0.3.1 the emergent properties of water

"**A single molecule of water**", thus, due to the interactions between many individual water molecules, "*ice displays buoyancy, crystalline organization, and hardness; water displays surface tension and viscosity. None of these properties is displayed by individual water molecules; what matter are dynamical regularities in the ways in which large numbers of these molecules interact with one another*" (Goodenough 2008:855).

Similarly, Ohm's Law is meaningless for a single copper atom and the Pauli exclusion principle does not apply to an isolated electron (Davies 2006:36).

George Johnson gives further examples of emergent properties (Johnson 1996:141). In the brain, neurons "*send signals back and forth and properties we call perception, intelligence, and consciousness arise*. … *Gas molecules jostling about in a container give rise to emergent qualities called temperature and pressure. But it is meaningless to speak of a single particle having a temperature or pressure just as it would be meaningless to say that a neuron is conscious or a water molecule is wet; these are ensemble properties that exist only on a higher level*".

It's not that you can't calculate or predict the bulk, collective behaviour of water from the properties of the separate H_2O molecules. For example, we can create realistic simulations of water in all 3 states (https://phet.colorado.edu/sims/html/states-of-matter-basics/latest/states-of-matter-basics_all.html), and we can watch salt dissolving (https://www.youtube.com/watch?v=dr4sFNzUVzI, and also https://phet.colorado.edu/sims/cheerpj/soluble-salts/latest/soluble-salts.html?simulation=soluble-salts). All viewed on 28 may 2025.

Clearly, some properties of liquid water are predictable from the properties of a single molecule. For example, knowing that the molecule is polar – has an imbalance of electric charge – one could predict the existence of hydrogen bonds, which dominate water's bulk properties (see sections 4.1.4 and 4.1.6).

A common approach is to say that the properties of the whole can't be predicted from the properties of its parts. For example, Ricard Solé observes that knowing the properties of a water molecule is not sufficient to predict the properties of liquid water, "*even though the behavior of water can be recognized to be consistent with the properties of its constituents*" (Solé 2000:13).

However, there seems to be little value in arguing how far one could calculate, and thereby predict, water's bulk properties. The real point is that these properties – predictable or not – are meaningless for a single molecule, or even for a small number of molecules. The bulk properties of any collective system have no meaning at the level of the separate parts; the new collective properties emerge and have meaning only at the bulk level. For example, buoyancy only means something when you have enough water to float the object; turbulence only means something when you have enough water to flow around it. A moderate-sized body of water, such as a lake, can sustain moderate-sized waves, but it's only an ocean-sized body of water that can sustain much bigger waves, from surfing waves to tsunamis.

Martin Chaplin has a comprehensive web-site on the properties of water, at https://water.lsbu.ac.uk/water/index.html.

Many of water's bulk properties can be understood without thinking of molecules at all – such as buoyancy, viscosity and turbulence (Tipler 1999:chapter 13, Bolton 2000:chapter 4).

In **figure 0.2**, the interactions between the water molecules can be attractive or repulsive, depending on their relative orientations, but for the sake of simplicity they are shown as double-headed arrows.

0.4 communities are bound by endless exchanges

0.5 explanations at their appropriate levels

"***Theory of Everything***", Laughlin 2000, who has observed that it is generally impossible to deduce the higher organising principles from the underlying behaviour of systems at a lower level.

"**This means that we can only explain events**", George Johnson observes that "*Our world is a whole wedding cake of layers. Subatomic particles obeying laws of quantum electrodynamics and quantum chromodynamics give rise to atoms and molecules obeying the laws of chemistry, which give rise to cells obeying the laws of biology and creatures obeying, to some extent, laws of psychology, sociology, and economics*" (Johnson 1996:140).

The happy converse of this is we can succeed and be effective with very limited knowledge. There is a "*hierarchical structure in Nature which permits us to understand the way in which aggregates of matter behave without the need to know the ultimate microstructure of matter down to the tiniest dimensions. … Fortunately, we do not need to know everything before we can know something*" (Barrow 1992:97).

reductionism and holism

Paul Davies views the main approach of Western scientific thinking over the last three centuries as being reductionist, that is, seeking to understand complex things by breaking them down into their component parts (Davies 1984:61 and 145). The alternative approach is to understand a complex thing by putting its components together, and this approach is described as synthetic or holistic. "*Reductionism seeks to uncover simple elements within complex structures, while holism directs attention to the complexity as a whole*" (Davies 1984:145). Paul Davies does not consider the reductionist and holistic descriptions to contradict each other, for "*the two viewpoints are complementary, each valid at their own level*" (Davies 1984:62).

A simple example of a synthetic system is a jigsaw, because the picture on a jigsaw "*can only be perceived at a higher level of structure than the individual pieces – the whole is greater than the sum of its parts*" (Davies 1984:61). So, a whole system has emergent qualities or properties that only appear "*at the collective level of structure, and are simply meaningless at the component level*" (Davies 1984:62). We must regard a whole system or thing as comprising the component parts ***plus*** the relationships between these parts. So, the individual jigsaw pieces each carry a part of the overall picture, and this picture is the emergent property that only becomes apparent when all the pieces are brought together in the right way (Davies 1984:62).

Herbert Simon gives a simple definition of a complex system as "*one made up of a large number of parts that interact in a nonsimple way*". In such a complex system, "*the whole is more than the sum of the parts, not in an ultimate, metaphysical sense, but in the important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole*. *In the face of complexity, an in-principle reductionist may be at the same time a pragmatic holist*" (both quotes from Simon 1962:468).

Ursula Goodenough and Terrence Deacon give a helpful view of the reductionist and holistic approaches (Goodenough 2008). They outline a reductionist break down of a human muscle, which reveals a sequence of diminishing structures: muscle cells, actin and myosin polymers, proteins, amino acids, and finally their component atoms.

However, while "*reductionism has yielded splendid results in science, there is an important sense in which it is artificial, and in this sense false. By starting from wholes and moving 'down' into parts, one is moving in the opposite direction from the way matters arise. To grasp how matters arise, one must run the muscle movie backwards, from the subatom to the atom to the amino acid to the protein to the polymer to the cell to the muscle to the contraction. To make such a movie, it is essential to begin with reductionist understandings—otherwise, there is no way to know what to put in the movie. But once the cast of characters is identified—once it is understood how proteins fold and myosin hydrolyses ATP and so on—it is possible to narrate such understandings in the correct temporal and spatial sequence, moving 'upwards' from one level to the next*" (Goodenough 2008:854).

These authors note that it's common to say that the whole is greater than the sum of its parts, but they make the more fundamental point that it's not "*that one encounters something greater or something more, but that one encounters something else altogether. Importantly, this something else can, in turn, participate in generating a new something else at a different level of organization. … The now widely adopted term to describe such dynamics is emergence. … Emergent properties arise as the consequence of relationships between entities*" (Goodenough 2008:854 and 855).

"The Communal Universe" is based on 3 centuries of reductionist analysis of the material world – taking the created universe apart, and seeing what it's made of. For useful overviews of this, see Capra 2016, chapters 1 and 2, and Hoffmann 2012, chapter 1. I've used this to derive a synthesis, in which I follow the universe as it evolves, so we see simple things coming together in new relationships to make more complex systems, and the universal hierarchy has emerged from this.

See also the note to section 9.1.3.

"**If we could observe a thought**", the brain operates as a hierarchy of systems, in which higher cognitive brain functions are carried out by bringing together sub-functions, so "*perception, language, thought, and memory are all made possible by the serial and parallel interlinking of several brain regions, each with specific functions*" (Kandel 2000:15).

"**So, a thought, a collective event**", see also the note to section 9.1.3.

Peter Hoffmann considers that there is "*no meaningful conceptual connection between a highly complex entity and the most fundamental levels of matter and energy*" (Hoffmann 2012:240).

0.6 Conclusion

references

Allday, J. (2002), *Quarks, Leptons and the Big Bang*, Institute of Physics Publishing, Bristol, 2nd edition.

Atkins, P. (1992), *Creation Revisited*, W. H. Freeman, Oxford and New York.

Atkins, P. (2018), *Conjuring the Universe: the origins of the laws of nature*, Oxford University Press.

Baggott, J. (2015), *Origins: the scientific story of creation*, Oxford University Press.

Barrow, J. (1992), *Theories of Everything: the quest for the ultimate explanation*, Vintage, London.

Bolton, J., editor (2000), *Classical Physics of Matter*, Institute of Physics Publishing, Bristol, in association with the Open University, Milton Keynes.

Bronowski, J. (1977), *A Sense of the Future,* MIT Press, Cambridge, MA.

Bryson, B. (2003), *A short History of Nearly Everything*, Doubleday, London.

Calvin, W. (1986), *The River that flows Uphill: a journey from the big bang to the big brain*, Sierra Club Books, San Francisco.

Calvin, W. (1997), *How Brains Think*, Weidenfeld and Nicolson, London.

Capra, F. and Luisi, P. L. (2016), *The Systems View of Life: a unifying vision*, Cambridge University Press, Cambridge.

Carroll, S. (2019), *Something Deeply Hidden: quantum worlds and the emergence of spacetime*, Oneworld Publications, London.

Chaisson, E. (2005), *Epic of Evolution: seven ages of the cosmos*, Columbia University Press, New York.

Christian, D. (2018), *Origin Story: a big history of everything*, Penguin, 2018.

Clayton, P. and Davies, P., editors (2006), *The Re-Emergence of Emergence: the emergentist hypothesis from science to religion*, Oxford University Press.

Close, F., Marten, M. and Sutton, C. (2004a), *The Particle Odyssey: a journey to the heart of matter*, Oxford University Press.

Close, F. (2007a), *The New Cosmic Onion: quarks and the nature of the universe*, Taylor and Francis, Boca Raton, Florida.

Davies, P. (2006), "The Physics of Downward Causation", chapter 2 in Clayton and Davies 2006.

Dawkins, R. (2005), *The Ancestor's Tale: a pilgrimage to the dawn of life*, Phoenix, London.

Delsemme, A. (1998), *Our Cosmic Origins: from the big bang to the emergence of life and intelligence*, Cambridge University Press.

Duff, B. (1986), *Fundamental Particles: an introduction to quarks and leptons*, Taylor and Francis, London.

Ellis, G. (2006), "On the Nature of Emergent Reality", chapter 4 in Clayton and Davies (2006).

Feynman, R. (1992), *The Character of Physical Law*, Penguin, London.

Ford, K. (1991), "The Large and the Small", p. 18−37 in *The World Treasury of Physics, Astronomy and Mathematics*, edited by T. Ferris (1991), Little, Brown and Company, Boston, MA.

Fortey, R. (1997), *Life: an Unauthorised Biography*, HarperCollins, London.

Freedman, R. and Kaufmann, W. (2002), *Universe*, W. H. Freeman, New York, 6th edition.

Gee, H. (2021), *A (very) Short History of Life on Earth*, Picador, London.

Gerrard, J. (2005), "Metabolism: chemistry of Life or Biology of Molecules?", page 536 in Garrett 2005.

Goodenough, U. and Deacon, T. (2008), "The Sacred Emergence of Nature", chapter 50 in "The Oxford Handbook of Religion and Science", edited by Philip Clayton and Zachary Simpson, Oxford University Press, Oxford, available online at https://openscholarship.wustl.edu/bio_facpubs/67/.

Gribbin, J. (1998), *Q is for Quantum: an encyclopedia of particle physics*, The Free Press, New York.

Gribbin, J. (2008), *The Universe: a biography*, Penguin, London.

Heyde, K. (1998), *From Nucleons to the Atomic Nucleus: perspectives in nuclear physics*, Springer-Verlag, Berlin.

Hoffmann, P. (2012), *Life's Ratchet: how molecular machines extract order from chaos*, Basic Books, New York.

Hogan, C. (1998), *The Little Book of the Big Bang: a cosmic primer*, Copernicus, New York, 2nd printing.

Holland, J. (2000), *Emergence: from Chaos to order*, Oxford University Press.

Jastrow, R. and Rampino, M. (2008), *Origins of Life in the Universe*, Cambridge University Press.

Johnson, G. (1996), *Fire in the Mind: science, faith and the search for order*, Viking, London.

Kandel, E. (2000), *Principles of Neural Science*, McGraw-Hill, New York, 4th edition.

Koestler, A. (1967), *The Ghost in the Machine*, Hutchinson, London.

Koestler, A. (1979), *Janus: a summing up*, Pan, London.

Krauss, L. (2002), *Atom: an odyssey from the big bang to life on earth…and beyond*, Abacus, London.

Laughlin, R. and Pines, D. (2000), "The Theory of Everything", *Proceedings of the National Academy of Sciences*, volume 97, p. 28−31.

Laughlin, R. (2006), *A Different Universe: reinventing physics from the bottom down*, Basic Books, New York.

Levi, P. (1986), *The Periodic Table*, Abacus, London.

Margulis, L. and Sagan, D. (1997), *Microcosmos: four billion years of evolution from our microbial ancestors*, University of California Press, Berkeley, California.

Morowitz, H. (2002), *The Emergence of Everything: how the world became complex*, Oxford University Press.

Needham, J. (1968), *Order and Life*, The M.I.T. Press, Cambridge, Massachusetts (first published in 1936).

Needham, J. (1986), *Time the Refreshing River*, Spokesman, Nottingham, England (first published in 1943).

Purves, W. et al. (1998), *Life: the science of biology*, Sinauer, Sunderland, Massachusetts, 5th edition.

Reeves, H. (1991), *The Hour of our Delight: cosmic evolution, order, and complexity*, W. H. Freeman, New York.

Rutherford, A. (2014), *Creation: the origin of life*, Penguin, London.

Sagan, C. (1981), *Cosmos*, Book Club Associates, London.

Simon, H. (1962), "The architecture of complexity", *Proceedings of the American Philosophical Society*, volume 106, pages 467−482.

Smith, J. M. and Szathmáry, E. (2000), *The Origins of Life: from the birth of life to the origins of language*, Oxford University Press.

Solé, R (2000), *Signs of Life: how complexity pervades biology*, Basic Books, New York.

Tipler, P. (1999), *Physics for Scientists and Engineers,* W. H. Freeman, New York, 4th edition.

Weinberg, S. (1993a), *The First Three Minutes: a modern view of the origin of the universe*, Basic Books, New York, revised 2nd edition.

Woolfson, A. (2000), *Life without Genes*, HarperCollins, London.

v.2 *July 2025*